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PASSBOOK® SERIES

THE *PASSBOOK® SERIES* has been created to prepare applicants and candidates for the ultimate academic battlefield — the examination room.

At some time in our lives, each and every one of us may be required to take an examination — for validation, matriculation, admission, qualification, registration, certification, or licensure.

Based on the assumption that every applicant or candidate has met the basic formal educational standards, has taken the required number of courses, and read the necessary texts, the *PASSBOOK® SERIES* furnishes the one special preparation which may assure passing with confidence, instead of failing with insecurity. Examination questions — together with answers — are furnished as the basic vehicle for study so that the mysteries of the examination and its compounding difficulties may be eliminated or diminished by a sure method.

This book is meant to help you pass your examination provided that you qualify and are serious in your objective.

The entire field is reviewed through the huge store of content information which is succinctly presented through a provocative and challenging approach — the question-and-answer method.

A climate of success is established by furnishing the correct answers at the end of each test.

You soon learn to recognize types of questions, forms of questions, and patterns of questioning. You may even begin to anticipate expected outcomes.

You perceive that many questions are repeated or adapted so that you can gain acute insights, which may enable you to score many sure points.

You learn how to confront new questions, or types of questions, and to attack them confidently and work out the correct answers.

You note objectives and emphases, and recognize pitfalls and dangers, so that you may make positive educational adjustments.

Moreover, you are kept fully informed in relation to new concepts, methods, practices, and directions in the field.

You discover that you are actually taking the examination all the time: you are preparing for the examination by "taking" an examination, not by reading extraneous and/or supererogatory textbooks.

In short, this PASSBOOK®, used directedly, should be an important factor in helping you to pass your test.

INSTRUMENTATION TECHNICIAN

DUTIES

Performs technical work in the maintenance and repair of instrumentation and motor control systems and related equipment. Maintains and repairs such instruments as magnetic flow meters, ultrasonic generators, differential pressure transmitters, rotometers, liquid level indicating systems, mag-flow convertors, adder-subtractors, square-root extractor totalizers, recorders and controllers. Utilizes such equipment as multimeters, analyzers, precision potentionmeters, voltmeters, amperometric titrators, oscilloscopes, signal generators and frequency counters. Insures proper and safe operation of all high-voltage plant electrical systems. Designs and implements modifications to motor control circuits. Does related work as required.

SCOPE OF THE EXAMINATION

The written test will cover knowledge, skills, and/or abilities in such areas as:

1. Inspection, operation, maintenance and repair of equipment used in instrumentation;
2. Inspection, operation, maintenance and repair of basic electrical equipment;
3. Operation, maintenance, and repair of pumps, motors, valves, mechanical and electrical equipment;
4. Reading and interpretation of plans and specifications; and
5. Tools of the trade.

HOW TO TAKE A TEST

I. YOU MUST PASS AN EXAMINATION

A. WHAT EVERY CANDIDATE SHOULD KNOW

Examination applicants often ask us for help in preparing for the written test. What can I study in advance? What kinds of questions will be asked? How will the test be given? How will the papers be graded?

As an applicant for a civil service examination, you may be wondering about some of these things. Our purpose here is to suggest effective methods of advance study and to describe civil service examinations.

Your chances for success on this examination can be increased if you know how to prepare. Those "pre-examination jitters" can be reduced if you know what to expect. You can even experience an adventure in good citizenship if you know why civil service exams are given.

B. WHY ARE CIVIL SERVICE EXAMINATIONS GIVEN?

Civil service examinations are important to you in two ways. As a citizen, you want public jobs filled by employees who know how to do their work. As a job seeker, you want a fair chance to compete for that job on an equal footing with other candidates. The best-known means of accomplishing this two-fold goal is the competitive examination.

Exams are widely publicized throughout the nation. They may be administered for jobs in federal, state, city, municipal, town or village governments or agencies.

Any citizen may apply, with some limitations, such as the age or residence of applicants. Your experience and education may be reviewed to see whether you meet the requirements for the particular examination. When these requirements exist, they are reasonable and applied consistently to all applicants. Thus, a competitive examination may cause you some uneasiness now, but it is your privilege and safeguard.

C. HOW ARE CIVIL SERVICE EXAMS DEVELOPED?

Examinations are carefully written by trained technicians who are specialists in the field known as "psychological measurement," in consultation with recognized authorities in the field of work that the test will cover. These experts recommend the subject matter areas or skills to be tested; only those knowledges or skills important to your success on the job are included. The most reliable books and source materials available are used as references. Together, the experts and technicians judge the difficulty level of the questions.

Test technicians know how to phrase questions so that the problem is clearly stated. Their ethics do not permit "trick" or "catch" questions. Questions may have been tried out on sample groups, or subjected to statistical analysis, to determine their usefulness.

Written tests are often used in combination with performance tests, ratings of training and experience, and oral interviews. All of these measures combine to form the best-known means of finding the right person for the right job.

II. HOW TO PASS THE WRITTEN TEST

A. NATURE OF THE EXAMINATION

To prepare intelligently for civil service examinations, you should know how they differ from school examinations you have taken. In school you were assigned certain definite pages to read or subjects to cover. The examination questions were quite detailed and usually emphasized memory. Civil service exams, on the other hand, try to discover your present ability to perform the duties of a position, plus your potentiality to learn these duties. In other words, a civil service exam attempts to predict how successful you will be. Questions cover such a broad area that they cannot be as minute and detailed as school exam questions.

In the public service similar kinds of work, or positions, are grouped together in one "class." This process is known as *position-classification.* All the positions in a class are paid according to the salary range for that class. One class title covers all of these positions, and they are all tested by the same examination.

B. FOUR BASIC STEPS

1) Study the announcement

How, then, can you know what subjects to study? Our best answer is: "Learn as much as possible about the class of positions for which you've applied." The exam will test the knowledge, skills and abilities needed to do the work.

Your most valuable source of information about the position you want is the official exam announcement. This announcement lists the training and experience qualifications. Check these standards and apply only if you come reasonably close to meeting them.

The brief description of the position in the examination announcement offers some clues to the subjects which will be tested. Think about the job itself. Review the duties in your mind. Can you perform them, or are there some in which you are rusty? Fill in the blank spots in your preparation.

Many jurisdictions preview the written test in the exam announcement by including a section called "Knowledge and Abilities Required," "Scope of the Examination," or some similar heading. Here you will find out specifically what fields will be tested.

2) Review your own background

Once you learn in general what the position is all about, and what you need to know to do the work, ask yourself which subjects you already know fairly well and which need improvement. You may wonder whether to concentrate on improving your strong areas or on building some background in your fields of weakness. When the announcement has specified "some knowledge" or "considerable knowledge," or has used adjectives like "beginning principles of..." or "advanced ... methods," you can get a clue as to the number and difficulty of questions to be asked in any given field. More questions, and hence broader coverage, would be included for those subjects which are more important in the work. Now weigh your strengths and weaknesses against the job requirements and prepare accordingly.

3) Determine the level of the position

Another way to tell how intensively you should prepare is to understand the level of the job for which you are applying. Is it the entering level? In other words, is this the position in which beginners in a field of work are hired? Or is it an intermediate or advanced level? Sometimes this is indicated by such words as "Junior" or "Senior" in the class title. Other jurisdictions use Roman numerals to designate the level – Clerk I, Clerk II, for example. The word "Supervisor" sometimes appears in the title. If the level is not indicated by the title,

check the description of duties. Will you be working under very close supervision, or will you have responsibility for independent decisions in this work?

4) Choose appropriate study materials

Now that you know the subjects to be examined and the relative amount of each subject to be covered, you can choose suitable study materials. For beginning level jobs, or even advanced ones, if you have a pronounced weakness in some aspect of your training, read a modern, standard textbook in that field. Be sure it is up to date and has general coverage. Such books are normally available at your library, and the librarian will be glad to help you locate one. For entry-level positions, questions of appropriate difficulty are chosen – neither highly advanced questions, nor those too simple. Such questions require careful thought but not advanced training.

If the position for which you are applying is technical or advanced, you will read more advanced, specialized material. If you are already familiar with the basic principles of your field, elementary textbooks would waste your time. Concentrate on advanced textbooks and technical periodicals. Think through the concepts and review difficult problems in your field.

These are all general sources. You can get more ideas on your own initiative, following these leads. For example, training manuals and publications of the government agency which employs workers in your field can be useful, particularly for technical and professional positions. A letter or visit to the government department involved may result in more specific study suggestions, and certainly will provide you with a more definite idea of the exact nature of the position you are seeking.

III. KINDS OF TESTS

Tests are used for purposes other than measuring knowledge and ability to perform specified duties. For some positions, it is equally important to test ability to make adjustments to new situations or to profit from training. In others, basic mental abilities not dependent on information are essential. Questions which test these things may not appear as pertinent to the duties of the position as those which test for knowledge and information. Yet they are often highly important parts of a fair examination. For very general questions, it is almost impossible to help you direct your study efforts. What we can do is to point out some of the more common of these general abilities needed in public service positions and describe some typical questions.

1) General information

Broad, general information has been found useful for predicting job success in some kinds of work. This is tested in a variety of ways, from vocabulary lists to questions about current events. Basic background in some field of work, such as sociology or economics, may be sampled in a group of questions. Often these are principles which have become familiar to most persons through exposure rather than through formal training. It is difficult to advise you how to study for these questions; being alert to the world around you is our best suggestion.

2) Verbal ability

An example of an ability needed in many positions is verbal or language ability. Verbal ability is, in brief, the ability to use and understand words. Vocabulary and grammar tests are typical measures of this ability. Reading comprehension or paragraph interpretation questions are common in many kinds of civil service tests. You are given a paragraph of written material and asked to find its central meaning.

3) Numerical ability

Number skills can be tested by the familiar arithmetic problem, by checking paired lists of numbers to see which are alike and which are different, or by interpreting charts and graphs. In the latter test, a graph may be printed in the test booklet which you are asked to use as the basis for answering questions.

4) Observation

A popular test for law-enforcement positions is the observation test. A picture is shown to you for several minutes, then taken away. Questions about the picture test your ability to observe both details and larger elements.

5) Following directions

In many positions in the public service, the employee must be able to carry out written instructions dependably and accurately. You may be given a chart with several columns, each column listing a variety of information. The questions require you to carry out directions involving the information given in the chart.

6) Skills and aptitudes

Performance tests effectively measure some manual skills and aptitudes. When the skill is one in which you are trained, such as typing or shorthand, you can practice. These tests are often very much like those given in business school or high school courses. For many of the other skills and aptitudes, however, no short-time preparation can be made. Skills and abilities natural to you or that you have developed throughout your lifetime are being tested.

Many of the general questions just described provide all the data needed to answer the questions and ask you to use your reasoning ability to find the answers. Your best preparation for these tests, as well as for tests of facts and ideas, is to be at your physical and mental best. You, no doubt, have your own methods of getting into an exam-taking mood and keeping "in shape." The next section lists some ideas on this subject.

IV. KINDS OF QUESTIONS

Only rarely is the "essay" question, which you answer in narrative form, used in civil service tests. Civil service tests are usually of the short-answer type. Full instructions for answering these questions will be given to you at the examination. But in case this is your first experience with short-answer questions and separate answer sheets, here is what you need to know:

1) Multiple-choice Questions

Most popular of the short-answer questions is the "multiple choice" or "best answer" question. It can be used, for example, to test for factual knowledge, ability to solve problems or judgment in meeting situations found at work.

A multiple-choice question is normally one of three types—

- It can begin with an incomplete statement followed by several possible endings. You are to find the one ending which *best* completes the statement, although some of the others may not be entirely wrong.
- It can also be a complete statement in the form of a question which is answered by choosing one of the statements listed.

- It can be in the form of a problem – again you select the best answer.

Here is an example of a multiple-choice question with a discussion which should give you some clues as to the method for choosing the right answer:

When an employee has a complaint about his assignment, the action which will *best* help him overcome his difficulty is to

A. discuss his difficulty with his coworkers
B. take the problem to the head of the organization
C. take the problem to the person who gave him the assignment
D. say nothing to anyone about his complaint

In answering this question, you should study each of the choices to find which is best. Consider choice "A" – Certainly an employee may discuss his complaint with fellow employees, but no change or improvement can result, and the complaint remains unresolved. Choice "B" is a poor choice since the head of the organization probably does not know what assignment you have been given, and taking your problem to him is known as "going over the head" of the supervisor. The supervisor, or person who made the assignment, is the person who can clarify it or correct any injustice. Choice "C" is, therefore, correct. To say nothing, as in choice "D," is unwise. Supervisors have and interest in knowing the problems employees are facing, and the employee is seeking a solution to his problem.

2) True/False Questions

The "true/false" or "right/wrong" form of question is sometimes used. Here a complete statement is given. Your job is to decide whether the statement is right or wrong.

SAMPLE: A roaming cell-phone call to a nearby city costs less than a non-roaming call to a distant city.

This statement is wrong, or false, since roaming calls are more expensive.

This is not a complete list of all possible question forms, although most of the others are variations of these common types. You will always get complete directions for answering questions. Be sure you understand *how* to mark your answers – ask questions until you do.

V. RECORDING YOUR ANSWERS

Computer terminals are used more and more today for many different kinds of exams.

For an examination with very few applicants, you may be told to record your answers in the test booklet itself. Separate answer sheets are much more common. If this separate answer sheet is to be scored by machine – and this is often the case – it is highly important that you mark your answers correctly in order to get credit.

An electronic scoring machine is often used in civil service offices because of the speed with which papers can be scored. Machine-scored answer sheets must be marked with a pencil, which will be given to you. This pencil has a high graphite content which responds to the electronic scoring machine. As a matter of fact, stray dots may register as answers, so do not let your pencil rest on the answer sheet while you are pondering the correct answer. Also, if your pencil lead breaks or is otherwise defective, ask for another.

Since the answer sheet will be dropped in a slot in the scoring machine, be careful not to bend the corners or get the paper crumpled.

The answer sheet normally has five vertical columns of numbers, with 30 numbers to a column. These numbers correspond to the question numbers in your test booklet. After each number, going across the page are four or five pairs of dotted lines. These short dotted lines have small letters or numbers above them. The first two pairs may also have a "T" or "F" above the letters. This indicates that the first two pairs only are to be used if the questions are of the true-false type. If the questions are multiple choice, disregard the "T" and "F" and pay attention only to the small letters or numbers.

Answer your questions in the manner of the sample that follows:

32. The largest city in the United States is
    - A. Washington, D.C.
    - B. New York City
    - C. Chicago
    - D. Detroit
    - E. San Francisco

1) Choose the answer you think is best. (New York City is the largest, so "B" is correct.)
2) Find the row of dotted lines numbered the same as the question you are answering. (Find row number 32)
3) Find the pair of dotted lines corresponding to the answer. (Find the pair of lines under the mark "B.")
4) Make a solid black mark between the dotted lines.

VI. BEFORE THE TEST

Common sense will help you find procedures to follow to get ready for an examination. Too many of us, however, overlook these sensible measures. Indeed, nervousness and fatigue have been found to be the most serious reasons why applicants fail to do their best on civil service tests. Here is a list of reminders:

- Begin your preparation early – Don't wait until the last minute to go scurrying around for books and materials or to find out what the position is all about.
- Prepare continuously – An hour a night for a week is better than an all-night cram session. This has been definitely established. What is more, a night a week for a month will return better dividends than crowding your study into a shorter period of time.
- Locate the place of the exam – You have been sent a notice telling you when and where to report for the examination. If the location is in a different town or otherwise unfamiliar to you, it would be well to inquire the best route and learn something about the building.
- Relax the night before the test – Allow your mind to rest. Do not study at all that night. Plan some mild recreation or diversion; then go to bed early and get a good night's sleep.
- Get up early enough to make a leisurely trip to the place for the test – This way unforeseen events, traffic snarls, unfamiliar buildings, etc. will not upset you.
- Dress comfortably – A written test is not a fashion show. You will be known by number and not by name, so wear something comfortable.

- Leave excess paraphernalia at home – Shopping bags and odd bundles will get in your way. You need bring only the items mentioned in the official notice you received; usually everything you need is provided. Do not bring reference books to the exam. They will only confuse those last minutes and be taken away from you when in the test room.
- Arrive somewhat ahead of time – If because of transportation schedules you must get there very early, bring a newspaper or magazine to take your mind off yourself while waiting.
- Locate the examination room – When you have found the proper room, you will be directed to the seat or part of the room where you will sit. Sometimes you are given a sheet of instructions to read while you are waiting. Do not fill out any forms until you are told to do so; just read them and be prepared.
- Relax and prepare to listen to the instructions
- If you have any physical problem that may keep you from doing your best, be sure to tell the test administrator. If you are sick or in poor health, you really cannot do your best on the exam. You can come back and take the test some other time.

VII. AT THE TEST

The day of the test is here and you have the test booklet in your hand. The temptation to get going is very strong. Caution! There is more to success than knowing the right answers. You must know how to identify your papers and understand variations in the type of short-answer question used in this particular examination. Follow these suggestions for maximum results from your efforts:

1) Cooperate with the monitor

The test administrator has a duty to create a situation in which you can be as much at ease as possible. He will give instructions, tell you when to begin, check to see that you are marking your answer sheet correctly, and so on. He is not there to guard you, although he will see that your competitors do not take unfair advantage. He wants to help you do your best.

2) Listen to all instructions

Don't jump the gun! Wait until you understand all directions. In most civil service tests you get more time than you need to answer the questions. So don't be in a hurry. Read each word of instructions until you clearly understand the meaning. Study the examples, listen to all announcements and follow directions. Ask questions if you do not understand what to do.

3) Identify your papers

Civil service exams are usually identified by number only. You will be assigned a number; you must not put your name on your test papers. Be sure to copy your number correctly. Since more than one exam may be given, copy your exact examination title.

4) Plan your time

Unless you are told that a test is a "speed" or "rate of work" test, speed itself is usually not important. Time enough to answer all the questions will be provided, but this does not mean that you have all day. An overall time limit has been set. Divide the total time (in minutes) by the number of questions to determine the approximate time you have for each question.

5) Do not linger over difficult questions

If you come across a difficult question, mark it with a paper clip (useful to have along) and come back to it when you have been through the booklet. One caution if you do this – be sure to skip a number on your answer sheet as well. Check often to be sure that you have not lost your place and that you are marking in the row numbered the same as the question you are answering.

6) Read the questions

Be sure you know what the question asks! Many capable people are unsuccessful because they failed to *read* the questions correctly.

7) Answer all questions

Unless you have been instructed that a penalty will be deducted for incorrect answers, it is better to guess than to omit a question.

8) Speed tests

It is often better NOT to guess on speed tests. It has been found that on timed tests people are tempted to spend the last few seconds before time is called in marking answers at random – without even reading them – in the hope of picking up a few extra points. To discourage this practice, the instructions may warn you that your score will be "corrected" for guessing. That is, a penalty will be applied. The incorrect answers will be deducted from the correct ones, or some other penalty formula will be used.

9) Review your answers

If you finish before time is called, go back to the questions you guessed or omitted to give them further thought. Review other answers if you have time.

10) Return your test materials

If you are ready to leave before others have finished or time is called, take ALL your materials to the monitor and leave quietly. Never take any test material with you. The monitor can discover whose papers are not complete, and taking a test booklet may be grounds for disqualification.

VIII. EXAMINATION TECHNIQUES

1) Read the general instructions carefully. These are usually printed on the first page of the exam booklet. As a rule, these instructions refer to the timing of the examination; the fact that you should not start work until the signal and must stop work at a signal, etc. If there are any *special* instructions, such as a choice of questions to be answered, make sure that you note this instruction carefully.

2) When you are ready to start work on the examination, that is as soon as the signal has been given, read the instructions to each question booklet, underline any key words or phrases, such as *least*, *best*, *outline*, *describe* and the like. In this way you will tend to answer as requested rather than discover on reviewing your paper that you *listed without describing*, that you selected the *worst* choice rather than the *best* choice, etc.

3) If the examination is of the objective or multiple-choice type – that is, each question will also give a series of possible answers: A, B, C or D, and you are called upon to select the best answer and write the letter next to that answer on your answer paper – it is advisable to start answering each question in turn. There may be anywhere from 50 to 100 such questions in the three or four hours allotted and you can see how much time would be taken if you read through all the questions before beginning to answer any. Furthermore, if you come across a question or group of questions which you know would be difficult to answer, it would undoubtedly affect your handling of all the other questions.

4) If the examination is of the essay type and contains but a few questions, it is a moot point as to whether you should read all the questions before starting to answer any one. Of course, if you are given a choice – say five out of seven and the like – then it is essential to read all the questions so you can eliminate the two that are most difficult. If, however, you are asked to answer all the questions, there may be danger in trying to answer the easiest one first because you may find that you will spend too much time on it. The best technique is to answer the first question, then proceed to the second, etc.

5) Time your answers. Before the exam begins, write down the time it started, then add the time allowed for the examination and write down the time it must be completed, then divide the time available somewhat as follows:
   - If 3-1/2 hours are allowed, that would be 210 minutes. If you have 80 objective-type questions, that would be an average of 2-1/2 minutes per question. Allow yourself no more than 2 minutes per question, or a total of 160 minutes, which will permit about 50 minutes to review.
   - If for the time allotment of 210 minutes there are 7 essay questions to answer, that would average about 30 minutes a question. Give yourself only 25 minutes per question so that you have about 35 minutes to review.

6) The most important instruction is to *read each question* and make sure you know what is wanted. The second most important instruction is to *time yourself properly* so that you answer every question. The third most important instruction is to *answer every question.* Guess if you have to but include something for each question. Remember that you will receive no credit for a blank and will probably receive some credit if you write something in answer to an essay question. If you guess a letter – say "B" for a multiple-choice question – you may have guessed right. If you leave a blank as an answer to a multiple-choice question, the examiners may respect your feelings but it will not add a point to your score. Some exams may penalize you for wrong answers, so in such cases *only*, you may not want to guess unless you have some basis for your answer.

7) Suggestions
   a. Objective-type questions
      1. Examine the question booklet for proper sequence of pages and questions
      2. Read all instructions carefully
      3. Skip any question which seems too difficult; return to it after all other questions have been answered
      4. Apportion your time properly; do not spend too much time on any single question or group of questions

5. Note and underline key words – *all, most, fewest, least, best, worst, same, opposite,* etc.
6. Pay particular attention to negatives
7. Note unusual option, e.g., unduly long, short, complex, different or similar in content to the body of the question
8. Observe the use of "hedging" words – *probably, may, most likely,* etc.
9. Make sure that your answer is put next to the same number as the question
10. Do not second-guess unless you have good reason to believe the second answer is definitely more correct
11. Cross out original answer if you decide another answer is more accurate; do not erase until you are ready to hand your paper in
12. Answer all questions; guess unless instructed otherwise
13. Leave time for review

b. Essay questions
1. Read each question carefully
2. Determine exactly what is wanted. Underline key words or phrases.
3. Decide on outline or paragraph answer
4. Include many different points and elements unless asked to develop any one or two points or elements
5. Show impartiality by giving pros and cons unless directed to select one side only
6. Make and write down any assumptions you find necessary to answer the questions
7. Watch your English, grammar, punctuation and choice of words
8. Time your answers; don't crowd material

8) Answering the essay question

Most essay questions can be answered by framing the specific response around several key words or ideas. Here are a few such key words or ideas:

M's: manpower, materials, methods, money, management
P's: purpose, program, policy, plan, procedure, practice, problems, pitfalls, personnel, public relations

a. Six basic steps in handling problems:
1. Preliminary plan and background development
2. Collect information, data and facts
3. Analyze and interpret information, data and facts
4. Analyze and develop solutions as well as make recommendations
5. Prepare report and sell recommendations
6. Install recommendations and follow up effectiveness

b. Pitfalls to avoid
1. *Taking things for granted* – A statement of the situation does not necessarily imply that each of the elements is necessarily true; for example, a complaint may be invalid and biased so that all that can be taken for granted is that a complaint has been registered

2. *Considering only one side of a situation* – Wherever possible, indicate several alternatives and then point out the reasons you selected the best one
3. *Failing to indicate follow up* – Whenever your answer indicates action on your part, make certain that you will take proper follow-up action to see how successful your recommendations, procedures or actions turn out to be
4. *Taking too long in answering any single question* – Remember to time your answers properly

IX. AFTER THE TEST

Scoring procedures differ in detail among civil service jurisdictions although the general principles are the same. Whether the papers are hand-scored or graded by machine we have described, they are nearly always graded by number. That is, the person who marks the paper knows only the number – never the name – of the applicant. Not until all the papers have been graded will they be matched with names. If other tests, such as training and experience or oral interview ratings have been given, scores will be combined. Different parts of the examination usually have different weights. For example, the written test might count 60 percent of the final grade, and a rating of training and experience 40 percent. In many jurisdictions, veterans will have a certain number of points added to their grades.

After the final grade has been determined, the names are placed in grade order and an eligible list is established. There are various methods for resolving ties between those who get the same final grade – probably the most common is to place first the name of the person whose application was received first. Job offers are made from the eligible list in the order the names appear on it. You will be notified of your grade and your rank as soon as all these computations have been made. This will be done as rapidly as possible.

People who are found to meet the requirements in the announcement are called "eligibles." Their names are put on a list of eligible candidates. An eligible's chances of getting a job depend on how high he stands on this list and how fast agencies are filling jobs from the list.

When a job is to be filled from a list of eligibles, the agency asks for the names of people on the list of eligibles for that job. When the civil service commission receives this request, it sends to the agency the names of the three people highest on this list. Or, if the job to be filled has specialized requirements, the office sends the agency the names of the top three persons who meet these requirements from the general list.

The appointing officer makes a choice from among the three people whose names were sent to him. If the selected person accepts the appointment, the names of the others are put back on the list to be considered for future openings.

That is the rule in hiring from all kinds of eligible lists, whether they are for typist, carpenter, chemist, or something else. For every vacancy, the appointing officer has his choice of any one of the top three eligibles on the list. This explains why the person whose name is on top of the list sometimes does not get an appointment when some of the persons lower on the list do. If the appointing officer chooses the second or third eligible, the No. 1 eligible does not get a job at once, but stays on the list until he is appointed or the list is terminated.

X. HOW TO PASS THE INTERVIEW TEST

The examination for which you applied requires an oral interview test. You have already taken the written test and you are now being called for the interview test – the final part of the formal examination.

You may think that it is not possible to prepare for an interview test and that there are no procedures to follow during an interview. Our purpose is to point out some things you can do in advance that will help you and some good rules to follow and pitfalls to avoid while you are being interviewed.

What is an interview supposed to test?

The written examination is designed to test the technical knowledge and competence of the candidate; the oral is designed to evaluate intangible qualities, not readily measured otherwise, and to establish a list showing the relative fitness of each candidate – as measured against his competitors – for the position sought. Scoring is not on the basis of "right" and "wrong," but on a sliding scale of values ranging from "not passable" to "outstanding." As a matter of fact, it is possible to achieve a relatively low score without a single "incorrect" answer because of evident weakness in the qualities being measured.

Occasionally, an examination may consist entirely of an oral test – either an individual or a group oral. In such cases, information is sought concerning the technical knowledges and abilities of the candidate, since there has been no written examination for this purpose. More commonly, however, an oral test is used to supplement a written examination.

Who conducts interviews?

The composition of oral boards varies among different jurisdictions. In nearly all, a representative of the personnel department serves as chairman. One of the members of the board may be a representative of the department in which the candidate would work. In some cases, "outside experts" are used, and, frequently, a businessman or some other representative of the general public is asked to serve. Labor and management or other special groups may be represented. The aim is to secure the services of experts in the appropriate field.

However the board is composed, it is a good idea (and not at all improper or unethical) to ascertain in advance of the interview who the members are and what groups they represent. When you are introduced to them, you will have some idea of their backgrounds and interests, and at least you will not stutter and stammer over their names.

What should be done before the interview?

While knowledge about the board members is useful and takes some of the surprise element out of the interview, there is other preparation which is more substantive. It *is* possible to prepare for an oral interview – in several ways:

1) Keep a copy of your application and review it carefully before the interview

This may be the only document before the oral board, and the starting point of the interview. Know what education and experience you have listed there, and the sequence and dates of all of it. Sometimes the board will ask you to review the highlights of your experience for them; you should not have to hem and haw doing it.

2) Study the class specification and the examination announcement

Usually, the oral board has one or both of these to guide them. The qualities, characteristics or knowledges required by the position sought are stated in these documents. They offer valuable clues as to the nature of the oral interview. For example, if the job

involves supervisory responsibilities, the announcement will usually indicate that knowledge of modern supervisory methods and the qualifications of the candidate as a supervisor will be tested. If so, you can expect such questions, frequently in the form of a hypothetical situation which you are expected to solve. NEVER go into an oral without knowledge of the duties and responsibilities of the job you seek.

3) Think through each qualification required

Try to visualize the kind of questions you would ask if you were a board member. How well could you answer them? Try especially to appraise your own knowledge and background in each area, *measured against the job sought*, and identify any areas in which you are weak. Be critical and realistic – do not flatter yourself.

4) Do some general reading in areas in which you feel you may be weak

For example, if the job involves supervision and your past experience has NOT, some general reading in supervisory methods and practices, particularly in the field of human relations, might be useful. Do NOT study agency procedures or detailed manuals. The oral board will be testing your understanding and capacity, not your memory.

5) Get a good night's sleep and watch your general health and mental attitude

You will want a clear head at the interview. Take care of a cold or any other minor ailment, and of course, no hangovers.

What should be done on the day of the interview?

Now comes the day of the interview itself. Give yourself plenty of time to get there. Plan to arrive somewhat ahead of the scheduled time, particularly if your appointment is in the fore part of the day. If a previous candidate fails to appear, the board might be ready for you a bit early. By early afternoon an oral board is almost invariably behind schedule if there are many candidates, and you may have to wait. Take along a book or magazine to read, or your application to review, but leave any extraneous material in the waiting room when you go in for your interview. In any event, relax and compose yourself.

The matter of dress is important. The board is forming impressions about you – from your experience, your manners, your attitude, and your appearance. Give your personal appearance careful attention. Dress your best, but not your flashiest. Choose conservative, appropriate clothing, and be sure it is immaculate. This is a business interview, and your appearance should indicate that you regard it as such. Besides, being well groomed and properly dressed will help boost your confidence.

Sooner or later, someone will call your name and escort you into the interview room. *This is it.* From here on you are on your own. It is too late for any more preparation. But remember, you asked for this opportunity to prove your fitness, and you are here because your request was granted.

What happens when you go in?

The usual sequence of events will be as follows: The clerk (who is often the board stenographer) will introduce you to the chairman of the oral board, who will introduce you to the other members of the board. Acknowledge the introductions before you sit down. Do not be surprised if you find a microphone facing you or a stenotypist sitting by. Oral interviews are usually recorded in the event of an appeal or other review.

Usually the chairman of the board will open the interview by reviewing the highlights of your education and work experience from your application – primarily for the benefit of the other members of the board, as well as to get the material into the record. Do not interrupt or comment unless there is an error or significant misinterpretation; if that is the case, do not

hesitate. But do not quibble about insignificant matters. Also, he will usually ask you some question about your education, experience or your present job – partly to get you to start talking and to establish the interviewing "rapport." He may start the actual questioning, or turn it over to one of the other members. Frequently, each member undertakes the questioning on a particular area, one in which he is perhaps most competent, so you can expect each member to participate in the examination. Because time is limited, you may also expect some rather abrupt switches in the direction the questioning takes, so do not be upset by it. Normally, a board member will not pursue a single line of questioning unless he discovers a particular strength or weakness.

After each member has participated, the chairman will usually ask whether any member has any further questions, then will ask you if you have anything you wish to add. Unless you are expecting this question, it may floor you. Worse, it may start you off on an extended, extemporaneous speech. The board is not usually seeking more information. The question is principally to offer you a last opportunity to present further qualifications or to indicate that you have nothing to add. So, if you feel that a significant qualification or characteristic has been overlooked, it is proper to point it out in a sentence or so. Do not compliment the board on the thoroughness of their examination – they have been sketchy, and you know it. If you wish, merely say, "No thank you, I have nothing further to add." This is a point where you can "talk yourself out" of a good impression or fail to present an important bit of information. Remember, *you close the interview yourself.*

The chairman will then say, "That is all, Mr. ______, thank you." Do not be startled; the interview is over, and quicker than you think. Thank him, gather your belongings and take your leave. Save your sigh of relief for the other side of the door.

How to put your best foot forward

Throughout this entire process, you may feel that the board individually and collectively is trying to pierce your defenses, seek out your hidden weaknesses and embarrass and confuse you. Actually, this is not true. They are obliged to make an appraisal of your qualifications for the job you are seeking, and they want to see you in your best light. Remember, they must interview all candidates and a non-cooperative candidate may become a failure in spite of their best efforts to bring out his qualifications. Here are 15 suggestions that will help you:

1) Be natural – Keep your attitude confident, not cocky

If you are not confident that you can do the job, do not expect the board to be. Do not apologize for your weaknesses, try to bring out your strong points. The board is interested in a positive, not negative, presentation. Cockiness will antagonize any board member and make him wonder if you are covering up a weakness by a false show of strength.

2) Get comfortable, but don't lounge or sprawl

Sit erectly but not stiffly. A careless posture may lead the board to conclude that you are careless in other things, or at least that you are not impressed by the importance of the occasion. Either conclusion is natural, even if incorrect. Do not fuss with your clothing, a pencil or an ashtray. Your hands may occasionally be useful to emphasize a point; do not let them become a point of distraction.

3) Do not wisecrack or make small talk

This is a serious situation, and your attitude should show that you consider it as such. Further, the time of the board is limited – they do not want to waste it, and neither should you.

4) Do not exaggerate your experience or abilities

In the first place, from information in the application or other interviews and sources, the board may know more about you than you think. Secondly, you probably will not get away with it. An experienced board is rather adept at spotting such a situation, so do not take the chance.

5) If you know a board member, do not make a point of it, yet do not hide it

Certainly you are not fooling him, and probably not the other members of the board. Do not try to take advantage of your acquaintanceship – it will probably do you little good.

6) Do not dominate the interview

Let the board do that. They will give you the clues – do not assume that you have to do all the talking. Realize that the board has a number of questions to ask you, and do not try to take up all the interview time by showing off your extensive knowledge of the answer to the first one.

7) Be attentive

You only have 20 minutes or so, and you should keep your attention at its sharpest throughout. When a member is addressing a problem or question to you, give him your undivided attention. Address your reply principally to him, but do not exclude the other board members.

8) Do not interrupt

A board member may be stating a problem for you to analyze. He will ask you a question when the time comes. Let him state the problem, and wait for the question.

9) Make sure you understand the question

Do not try to answer until you are sure what the question is. If it is not clear, restate it in your own words or ask the board member to clarify it for you. However, do not haggle about minor elements.

10) Reply promptly but not hastily

A common entry on oral board rating sheets is “candidate responded readily,” or “candidate hesitated in replies.” Respond as promptly and quickly as you can, but do not jump to a hasty, ill-considered answer.

11) Do not be peremptory in your answers

A brief answer is proper – but do not fire your answer back. That is a losing game from your point of view. The board member can probably ask questions much faster than you can answer them.

12) Do not try to create the answer you think the board member wants

He is interested in what kind of mind you have and how it works – not in playing games. Furthermore, he can usually spot this practice and will actually grade you down on it.

13) Do not switch sides in your reply merely to agree with a board member

Frequently, a member will take a contrary position merely to draw you out and to see if you are willing and able to defend your point of view. Do not start a debate, yet do not surrender a good position. If a position is worth taking, it is worth defending.

14) Do not be afraid to admit an error in judgment if you are shown to be wrong

The board knows that you are forced to reply without any opportunity for careful consideration. Your answer may be demonstrably wrong. If so, admit it and get on with the interview.

15) Do not dwell at length on your present job

The opening question may relate to your present assignment. Answer the question but do not go into an extended discussion. You are being examined for a *new* job, not your present one. As a matter of fact, try to phrase ALL your answers in terms of the job for which you are being examined.

Basis of Rating

Probably you will forget most of these “do’s” and “don’ts” when you walk into the oral interview room. Even remembering them all will not ensure you a passing grade. Perhaps you did not have the qualifications in the first place. But remembering them will help you to put your best foot forward, without treading on the toes of the board members.

Rumor and popular opinion to the contrary notwithstanding, an oral board wants you to make the best appearance possible. They know you are under pressure – but they also want to see how you respond to it as a guide to what your reaction would be under the pressures of the job you seek. They will be influenced by the degree of poise you display, the personal traits you show and the manner in which you respond.

ABOUT THIS BOOK

This book contains tests divided into Examination Sections. Go through each test, answering every question in the margin. We have also attached a sample answer sheet at the back of the book that can be removed and used. At the end of each test look at the answer key and check your answers. On the ones you got wrong, look at the right answer choice and learn. Do not fill in the answers first. Do not memorize the questions and answers, but understand the answer and principles involved. On your test, the questions will likely be different from the samples. Questions are changed and new ones added. If you understand these past questions you should have success with any changes that arise. Tests may consist of several types of questions. We have additional books on each subject should more study be advisable or necessary for you. Finally, the more you study, the better prepared you will be. This book is intended to be the last thing you study before you walk into the examination room. Prior study of relevant texts is also recommended. NLC publishes some of these in our Fundamental Series. Knowledge and good sense are important factors in passing your exam. Good luck also helps. So now study this Passbook, absorb the material contained within and take that knowledge into the examination. Then do your best to pass that exam.

EXAMINATION SECTION

EXAMINATION SECTION
TEST 1

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. A piece of equipment listed as drawing 100 watts is plugged into a 24 volt DC circuit. The MINIMUM size fuse which would handle this load is _______ amps. 1.____

   A. 2 B. 3 C. 4 D. 5

2. A resistor of 1000 ohms has 3 milliamperes passing through it. The voltage drop across the resistor is _______ volts. 2.____

   A. 3 B. 6 C. 15 D. 300

3. A certain resistor has three colored bands around it. The one nearest the end is green, the next one is orange, and the next one is red. The value of this register is _______ ohms. 3.____

   A. 74 B. 270 C. 5300 D. 64,000

4. An alternating voltage is applied to a capacitor. As the frequency of this voltage is increased, the impedance of the capacitor 4.____

   A. increases
   B. decreases
   C. remains the same
   D. increases or decreases depending on its construction

5. The one of the following that is NOT a part of a transistor is the 5.____

   A. emitter B. collector C. base D. grid

6. A 0.2 ufd capacitor is connected in series with a 0.1 ufd capacitor. The resultant capacity is _______ ufd. 6.____

   A. 0.067 B. 0.67 C. 0.15 D. 0.3

7. The term *Hertz* means the same as 7.____

   A. degrees Centigrade B. degrees Fahrenheit
   C. revolutions per minute D. cycles per second

8. In an electrolytic condenser, the dielectric material is 8.____

   A. mylar B. aluminum oxide
   C. paper D. sodium chloride

9. The amount by which a transformer will step up or step down a voltage is determined by its 9.____

   A. inductance B. resistance
   C. magnetic flux D. turns ratio

10. The electrolyte in a lead plate storage battery (such as that used in cars) is 1

A. aluminum hydroxide
B. sulfuric acid
C. hydrochloric acid
D. sodium chloride

11. A diode in an electronic circuit is used to 1

A. amplify
B. oscillate
C. attenuate
D. rectify

12. The MAIN function of a filter in a power supply is to 1

A. increase the voltage
B. decrease the load
C. smooth out the peaks of the ripple frequency
D. protect the power transformer

13. The expression *pH* as applied to a liquid refers to its 1

A. salinity
B. specific gravity
C. viscosity
D. acidity/alkalinity

14. The speed of a synchronous motor is controlled by 1

A. the voltage applied to it
B. the frequency of the alternating current applied to it
C. a mechanical governor
D. the current it draws

15. The capacitance of a condenser is measured in 1

A. oersteds
B. ohms
C. henrys
D. farads

16. The power lost in a 20-ohm resistor, with 0.25 amperes passing through it, is _______ watts. 1

A. 0.04
B. 0.4
C. 1.25
D. 5

17. When soldering a transistor into a circuit, it is good practice to clamp a pair of long-nosed pliers on the lead between the transistor and the end being soldered. 1
This is done to

A. prevent the lead from moving
B. prevent burning the fingers
C. ground the transistor
D. prevent the soldering iron's heat from reaching the transistor

18. The commutator of a motor should 1

A. not be lubricated
B. be lubricated with light oil
C. be lubricated with heavy grease
D. be lubricated with hypoid oil

19. The band of wavelengths of visible light covers 1

A. 20-50 centimeters
B. 10-50 meters
C. 400-700 millimicrons
D. 400-700 millimeters

20. The heat reaching the earth from the sun is transmitted by 20.____

A. ions
B. convection
C. radiation
D. cosmic rays

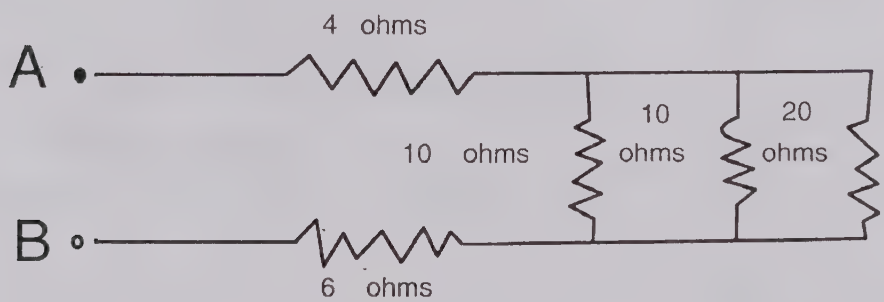
21. A *thermistor* is a 21.____

A. type of thermometer
B. high power transistor
C. water heating device
D. resistor with a negative temperature coefficient

22. In an AC circuit, the term *power factor* refers to the 22.____

A. horsepower
B. BTU per watt
C. ratio of the resistance to the impedance
D. kilowatts per horsepower

23. 23.____



In the above circuit, the TOTAL resistance between points A and B is _______ ohms.

A. 5
B. 14
C. 20
D. 45

24. Of the four gases listed below, the one that is NOT an air pollutant is 24.____

A. carbon dioxide
B. carbon monoxide
C. sulfur dioxide
D. hydrogen sulfide

25. The term *milli-roentgen* refers to a unit of 25.____

A. x-ray radiation
B. ultraviolet radiation
C. reluctance
D. inductance

26. An AC motor drawing 12 amps is plugged into a 15-amp circuit. The starting surge of the motor, however, is 18 amps. 26.____
The PROPER type of fuse to be used in this situation is

A. varistor
B. thermistor
C. fast-blow
D. slow-blow

27. Degrees Kelvin is numerically equal to degrees 27.____

A. Fahrenheit - 15
B. Centigrade + 27
C. Fahrenheit + 135
D. Centigrade + 273

28. In the term *micromicrofarads,* the prefix *micromicro* means multiply by

A. 10^6 B. 10^3 C. 10^{-12} D. 10^{-6}

29. One horsepower is equivalent to

A. 276 joules
B. 746 kilowatts
C. 746 watts
D. 291 calories

30. Laminated iron or steel is generally used instead of solid metal in the construction of the field and armature cores in motors and generators.
The reason for this is to

A. reduce eddy current losses
B. increase the voltage
C. decrease the flux
D. reduce the cost

31. The instrument used to measure current flow is called a(n)

A. wattmeter
B. voltmeter
C. ammeter
D. wavemeter

32. Reversing the polarity of the voltage applied to a mica condenser will

A. destroy it
B. increase its capacity
C. decrease its capacity
D. have no effect on it

33. The *decibel* is the unit used for expressing

A. light levels
B. DC voltage
C. AC current
D. the ratio between two quantities of either electrical or sound energy

34. In a three-phase Y-connected AC power system, the voltage from leg to ground is 120 volts.
The voltage between each pair of hot legs is ______ volts.

A. 160 B. 180 C. 208 D. 240

35. An hygrometer is an instrument which measures

A. humidity
B. temperature
C. specific gravity
D. luminosity

36. The impedance ratio of a transformer varies ______ the turns ratio.

A. directly with
B. as the square of
C. as the square root of
D. inversely with

37. Two resistors are connected in series. The current through these resistors is 3 amperes. Resistance #1 has a value of fifty ohms; resistance #2 has a voltage drop of fifty volts across its terminals.
The TOTAL impressed voltage (across both resistors) is ______ volts.

A. 100 B. 150 C. 200 D. 250

38. The piece of equipment that should be used to obtain more than one voltage from a fixed voltage direct current source is a(n) 38.____

A. multitap transformer
B. resistance-type voltage divider
C. autotransformer
D. copper oxide rectifier

39. The ratio of peak to effective (rms) voltage value of a sine wave is 39.____

A. 2 to 1 B. 1 to 2 C. .707 to 1 D. 1.414 to 1

40. Two coils are connected in series.
If there is no mutual inductance between the coils, the TOTAL inductance of the two coils is the _______ inductances. 40.____

A. sum of the individual
B. product of the individual
C. product of the square roots of the two
D. sum of the squares of the individual

41. The impedance of a coil with zero resistance is called the 41.____

A. reluctance
B. conductance
C. inductive reactance
D. flux

42. The ratio of the energy stored to the energy lost in a coil over a period of one cycle is called its 42.____

A. efficiency
B. Q
C. reactance
D. resistance

43. In a vacuum tube, the current is carried by 43.____

A. ions B. neutrons C. electrons D. molecules

44. The device used to vary the intensity of an incandescent light on a 120V AC circuit is a 44.____

A. variable capacitor
B. silicon controlled rectifier
C. copper oxide rectifier
D. rf amplifier

45. High power transistors must be mounted on *heat sinks*. The purpose of the heat sinks is to 45.____

A. improve voltage regulation
B. increase the transistors' output
C. keep the transistors warm
D. keep the transistors cool

46. The one of the following materials that has the HIGHEST conductivity is 46.____

A. iron B. zinc C. copper D. silver

47. The unit used to express the alternating current impedance of a circuit is the

A. mho B. farad C. ohm D. rel

48. A certain resistor has four colored bands on it. The fourth band is gold.
This means that the resistor

A. is wirewound
B. is non-inductive
C. has a ± 20% tolerance
D. has a ± 5% tolerance

49. An amplifier has an output voltage waveform that does not exactly follow that of the input voltage.
This type of distortion is called _______ distortion.

A. modular
B. frequency
C. resonance
D. amplitude

50. A parallel circuit, resonant at 1000 khz, has its value of capacity doubled and its value of inductance halved.
Its resonant frequency now is _______ khz.

A. 500 B. 1000 C. 1500 D. 2000

KEY (CORRECT ANSWERS)

1.	D	11.	D	21.	D	31.	C	41.	C
2.	A	12.	C	22.	C	32.	D	42.	B
3.	C	13.	D	23.	B	33.	D	43.	C
4.	B	14.	B	24.	A	34.	C	44.	B
5.	D	15.	D	25.	A	35.	A	45.	D
6.	A	16.	C	26.	D	36.	B	46.	D
7.	D	17.	D	27.	D	37.	C	47.	C
8.	B	18.	A	28.	C	38.	B	48.	D
9.	D	19.	C	29.	C	39.	D	49.	D
10.	B	20.	C	30.	A	40.	A	50.	B

TEST 2

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. A voltmeter which reads 100V full scale has a specified accuracy of 3%. It is hooked across a circuit and reads 97 volts. 1.____
The TRUE voltage can be assumed to be somewhere between

   A. 96.7 and 97.3
   B. 94 and 100
   C. 96.07 and 97.03
   D. 95.5 and 98.5

2. The product of 127.2 and .0037 is 2.____

   A. 4706.4 B. 470.64 C. .47064 D. .0047064

3. The wind velocity at a certain location was measured four times in a 24-hour period. The readings were 32 mph, 10 mph, 16 mph, and 2 mph. 3.____
The AVERAGE wind velocity for that day was _______ mph.

   A. 24 B. 20 C. 15 D. 13

4. When 280 is divided by .014, the answer is 4.____

   A. .002 B. 20 C. 200 D. 20,000

5. The square root of 289 is 5.____

   A. 1.7 B. 9.7 C. 17 D. 144.5

6. The watts drawn by a resistive load is to be determined. To do this, a voltmeter (10V full scale) is connected across the load, and an ammeter (10 amps full scale) is connected in series with the load. Both instruments are specified as having 1% (full scale) accuracy. 6.____
The voltmeter reads 9.2V; the ammeter reads 8.3 amps.
The MOST valid value for the watts drawn is _______ watts.

   A. 76 B. 76.36 C. 76.4 D. 80

7. The formula for converting degrees Centigrade to degrees Fahrenheit is: $^{\circ}F = (9/5).(^{\circ}C) + 32$. 7.____
A temperature of 25° C is equal to

   A. 102.6° F B. 85° F C. 77° F D. 43° F

8. The prefix *kilo* means 8.____

   A. multiply by one million
   B. divide by one million
   C. multiply by one thousand
   D. divide by one hundred

9. 2^8 is equal to 9.____

   A. 512 B. 256 C. 124 D. 82

10. The prefix *milli* means

A. multiply by 100
B. divide by one thousand
C. divide by one million
D. multiply by one million

11. If 1/X = 1/20 + 1/20 + 1/40, the value of X is

A. .125
B. 8
C. 16
D. 20

12. 2×10^6 multiplied by 4×10^{-6} equals

A. 8
B. 8×10^{-12}
C. 8×10^{12}
D. 8×10^3

13. 1 inch equals _______ cm.

A. 0.62
B. 2.54
C. 3.94
D. 16.2

14. 1 kg equals

A. 2.2 lbs.
B. 17.3 oz.
C. 0.52 lbs.
D. 12 oz.

15. 1 liter equals

A. 3.78 quarts
B. 1.057 quarts
C. 1.39 pints
D. .067 gallons

16. A circle has a radius of 10 inches.
Its circumference is _______ inches.

A. 72.3
B. 62.8
C. 31.4
D. 25

17. A right angle triangle has sides measuring 3 inches and 4 inches; its hypotenuse is 5 inches.
The area of this triangle is _______ square inches.

A. 6
B. 20
C. 15
D. 60

18. A square has an area of 81 square inches.
The length of each side is _______ inches.

A. 7.9
B. 9
C. 11
D. 17

19. A bottle contains 11 pints of liquid. To this bottle 1.32 pints is then added.
This is an increase of

A. 6%
B. 9%
C. 12%
D. 16%

20. A week ago a storage battery read 12.4V. Today its voltage is 8.1% less.
Its voltage is now

A. 11.4
B. 10.8
C. 9.3
D. 10.2

21. The advantage of a vacuum tube voltmeter over a regular voltmeter is that it

A. operates on batteries
B. operates on 120V AC
C. has a low input impedance
D. has a high input impedance

22. A g_m tube tester measures a vacuum tube's 22.____

A. capacitance
B. resistance
C. emission
D. transconductance

23. A cathode ray tube is used in a(n) 23.____

A. audio amplifier
B. radio frequency amplifier
C. oscilloscope
D. volt-ohm-milliammeter

24. A voltmeter is described as having *1000 ohms per volt.* The current required to produce full scale deflection is 24.____

A. 1 milliampere
B. 1 ampere
C. 20 milliamperes
D. 0.05 milliamperes

25. The PRIMARY use of a test oscilloscope is to 25.____

A. analyze complex waveforms
B. measure resistance
C. measure capacitance
D. measure DC voltages

26. A spectrophotometer is an instrument that measures 26.____

A. photographic film density
B. the amount of light of a particular wavelength
C. the amount of airborne dust
D. x-ray radiation

27. The test instrument generally known as a *multitester* will measure, among other things, 27.____

A. temperature
B. beta radiation
C. AC watts
D. DC milliamperes

28. A lightmeter used in measuring incident light gives readings in 28.____

A. footcandles
B. candlepower
C. lumens
D. foot-lamberts

29. A selenium photocell is a type known as photo- 29.____

A. emissive
B. resistive
C. voltaic
D. transistive

30. In wiring electronic circuits, the solder GENERALLY used is _______ solder. 30.____

A. silver
B. acid core
C. aluminum
D. rosin core

31. An unconscious victim of electric shock should be orally administered 31.____

A. nothing
B. coffee
C. alcohol
D. aromatic apirits of ammonia

32. Persons operating x-ray equipment should wear

    A. safety goggles
    B. insulating gloves
    C. a lead-coated apron and gloves
    D. a surgical mask

33. Harmful radiation is emitted by the element

    A. neon   B. lithium   C. platinum   D. radium

34. When a victim of electrical shock or near drowning is given artificial respiration and he does not appear to respond, the treatment should continue for at least

    A. four hours   B. fifteen minutes
    C. five minutes   D. fifteen hours

35. A person maintaining high voltage equipment should avoid wearing

    A. long hair
    B. sneakers
    C. rings and metallic watchbands
    D. eyeglasses

36. Portable AC equipment is often equipped with a three-wire cable and a three-prong male plug.
    The reason for this is to prevent

    A. radiation   B. electric shock
    C. oscillation   D. ground currents

37. Smoke is seen issuing from a piece of electronic equipment. The FIRST thing that should be done is to

    A. call the fire department
    B. pour water on it
    C. look for a fire extinguisher
    D. shut off the power

38. A match should not be used when inspecting the electrolyte level in a lead-acid battery because the cells emit

    A. nitrogen   B. hydrogen
    C. carbon dioxide   D. sulfur dioxide

39. A person feels nauseated, his mental capacity has been lowered, and he has a severe throbbing headache. It is suspected that he has been poisoned by gas, but there is no apparent odor.
    The poisonous gas is MOST likely to be

    A. sulfur dioxide   B. hydrogen cyanide
    C. carbon monoxide   D. chlorine

40. The purpose of an interlock on a piece of electronic equipment is to 40.___

A. prevent theft of the vacuum tubes
B. prevent electrical shock to maintenance personnel
C. prevent rf radiation
D. keep the equipment cool

41. An alternating voltage is applied to an inductance. 41.___
As the frequency of the voltage is decreased, the impedance of the inductance

A. decreases
B. increases
C. follows the alternating voltage
D. remains the same

42. A 0.25 ufd condenser is connected in parallel with a 0.50 ufd condenser. 42.___
The resultant capacity is ______ ufd.

A. 0.167 B. 0.37 C. 0.75 D. 2.5

43. The electrolyte in a carbon-zinc dry cell is 43.___

A. sulfuric acid
B. ammonium chloride
C. lithium chloride
D. sodium chloride

44. A 5000-ohm resistor has a voltage of 25 volts applied to it. 44.___
The current drawn by the resistor is

A. 5 milliamperes
B. 5 amperes
C. 75 milliamperes
D. 1.25 milliamperes

45. A certain resistor has three colored bands around it. 45.___
The one nearest the end is red, the next one is gray, and the next one is yellow.
The value of the resistor is

A. 2.7 megaohms
B. 280,000 ohms
C. 3270 ohms
D. 449 ohms

Questions 46-50.

DIRECTIONS: Questions 46 through 50 are to be answered on the basis of the following paragraph.

The second half of the twin triode acts as a phase modulator. The rf output of the crystal oscillator is impressed on the phase-modulator grid by means of a blocking condenser. The cathode circuit is provided with a large amount of degeneration by an un-bypassed cathode resistor. Because of this degenerative feedback, the transconductance of the triode is abnormally low, so low that the plate current is affected as much by the direct grid-plate capacitance as by the transconductance. The two effects result in plate current vectors almost 180° apart, and the total plate current is the resultant of the two components. In phase, it will be about 90° removed from the phase of the voltage impressed on the grid.

46. As used in the above paragraph, the word *impressed* means MOST NEARLY 4

A. applied B. blocked C. changed D. detached

47. As used in the above paragraph, the word *components* refers to the 4

A. blocking condenser and cathode resistor
B. twin triode
C. plate current vectors
D. grid-plate capacitance

48. According to the above paragraph, degenerative feedback is obtained by means of 4

A. a crystal oscillator
B. the plate voltage
C. an un-bypassed cathode resistor
D. a blocking condenser

49. According to the above paragraph, the cathode resistor is 4

A. very large
B. not bypassed
C. in series with an inductance
D. shunted by a blocking condenser

50. According to the above paragraph, the phase angle between the grid voltage and the total plate current is APPROXIMATELY 5

A. 180° B. 90° C. 270° D. zero

KEY (CORRECT ANSWERS)

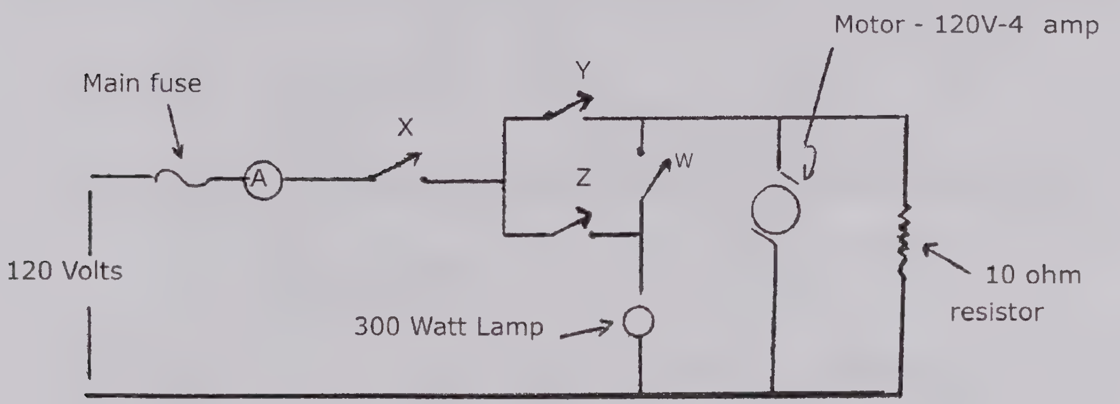
1.	B	11.	B	21.	D	31.	A	41.	A
2.	C	12.	C	22.	D	32.	C	42.	C
3.	C	13.	B	23.	C	33.	D	43.	B
4.	D	14.	A	24.	A	34.	A	44.	A
5.	C	15.	B	25.	A	35.	C	45.	B
6.	A	16.	B	26.	B	36.	B	46.	A
7.	C	17.	A	27.	D	37.	D	47.	C
8.	C	18.	B	28.	A	38.	B	48.	C
9.	B	19.	C	29.	C	39.	C	49.	B
10.	B	20.	A	30.	D	40.	B	50.	B

EXAMINATION SECTION
TEST 1

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

Questions 1-6.

DIRECTIONS: Questions 1 through 6 are to be answered on the basis of the circuit diagram below. All switches are initially open.



1. To light the 300 watt lamp, the following switches MUST be closed: 1._____

    A. X and Y B. Y and Z C. X and Z D. X and W

2. If all of the switches W, X, Y, and Z are closed, the following will happen: 2._____

    A. The lamp will light and the motor will rotate
    B. The lamp will light and the motor will not rotate
    C. The lamp will not light and the motor will not rotate
    D. A short circuit will occur and the main fuse will blow

3. With 120 volts applied across the 10 ohm resistor, the current drawn by the resistor is _______ amp(s). 3._____

    A. 1/12 B. 1.2 C. 12 D. 1200

4. With 120 volts applied to the 10 ohm resistor, the power used by the resistor is _______ kw. 4._____

    A. 1.44 B. 1.2 C. .144 D. .12

5. The current drawn by the 300 watt lamp when lighted should be APPROXIMATELY _______ amps. 5._____

    A. 2.5 B. 3.6 C. 25 D. 36

6. In the circuit shown, the symbol A is used to indicate a (n) 6._

A. ammeter
B. *and* circuit
C. voltmeter
D. wattmeter

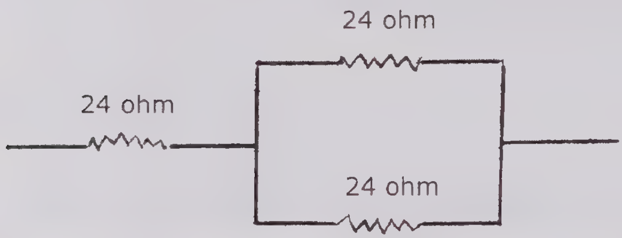
7. Of the following materials, the BEST conductor of electricity is 7._

A. iron B. copper C. aluminum D. glass

8. The sum of 6'6", 5'9", and 2' 1 1/2" is 8._

A. 13'4 1/2" B. 13'6 1/2" C. 14'4 1/2" D. 14'6 1/2"

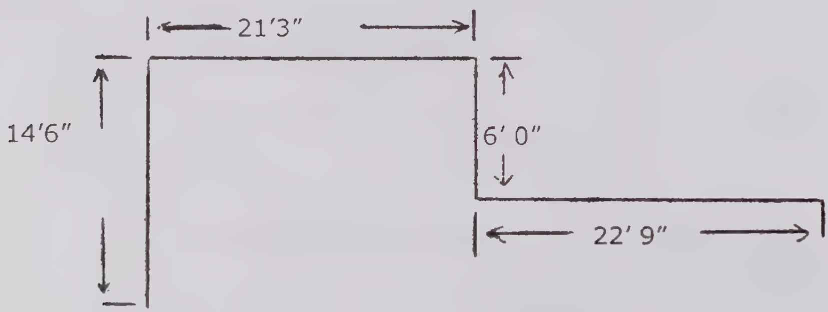
9. 9._



The equivalent resistance of the three resistors shown in the sketch above is _______ ohms.

A. 8 B. 24 C. 36 D. 72

10. 10._



The TOTAL length of electrical conduit that must be run along the path shown on the diagram above is

A. 63'8" B. 64'6" C. 65'6" D. 66'8"

11. Of the following electrical devices, the one that is NOT normally used in direct current electrical circuits is a (n) 11._

A. circuit breaker
B. double-pole switch
C. transformer
D. inverter

12. The number of 120-volt light bulbs that should NORMALLY be connected in series across a 600-volt electric line is 12._

A. 1 B. 2 C. 3 D. 5

13. Of the following motors, the one that does NOT have any brushes is the ______ motor. 13.____

A. d.c. shunt
B. d.c. series
C. squirrel cage induction
D. compound

14. Of the following materials, the one that is COMMONLY used as an electric heating element in an electric heater is 14.____

A. zinc
B. brass
C. terne plate
D. nichrome

Questions 15-25.

DIRECTIONS: Questions 15 through 25 are to be answered on the basis of the instruments listed below. Each instrument is listed with an identifying number in front of it.

1 - Hygrometer
2 - Ammeter
3 - Voltmeter
4 - Wattmeter
5 - Megger
6 - Oscilloscope
7 - Frequency meter
8 - Micrometer
9 - Vernier caliper
10 - Wire gage
11 - 6-foot folding rule
12 - Architect's scale
13 - Planimeter
14 - Engineer's scale
15 - Ohmmeter

15. The instrument that should be used to accurately measure the resistance of a 4,700 ohm resistor is Number 15.____

A. 3
B. 4
C. 7
D. 15

16. To measure the current in an electrical circuit, the instrument that should be used is Number 16.____

A. 2
B. 7
C. 8
D. 15

17. To measure the insulation resistance of a rubber-covered electrical cable, the instrument that should be used is Number 17.____

A. 4
B. 5
C. 8
D. 15

18. An AC motor is hooked up to a power distribution box.
In order to check the voltage at the motor terminals, the instrument that should be used is Number 18.____

A. 2
B. 3
C. 4
D. 7

19. To measure the shaft diameter of a motor accurately to one-thousandth of an inch, the instrument that should be used is Number 19.____

A. 8
B. 10
C. 11
D. 14

20. The instrument that should be used to determine whether 25 Hz. or 60 Hz. is present in an electrical circuit is Number 20.____

A. 4
B. 5
C. 7
D. 8

21. Of the following, the PROPER instrument to use to determine the diameter of the conductor of a piece of electrical hook-up wire is Number 21.___

A. 10 B. 11 C. 12 D. 14

22. The amount of electrical power being used in a balanced three-phase circuit should be measured with Number 22.___

A. 2 B. 3 C. 4 D. 5

23. The electrical wave form at a given point in an electronic circuit can be observed with Number 23.___

A. 2 B. 3 C. 6 D. 7

24. The PROPER instrument to use for measuring the width of a door is Number 24.___

A. 11 B. 12 C. 13 D. 14

25. A one-inch hole with a tolerance of plus or minus three-thousandths is reamed in a steel block. 25.___
The PROPER instrument to use to accurately check the diameter of the hole is Number

A. 8 B. 9 C. 11 D. 14

KEY (CORRECT ANSWERS)

1.	C	11.	C
2.	A	12.	D
3.	C	13.	C
4.	A	14.	D
5.	A	15.	D
6.	A	16.	A
7.	B	17.	B
8.	C	18.	B
9.	C	19.	A
10.	B	20.	C

21. A
22. C
23. C
24. A
25. B

TEST 2

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. The number of conductors required to connect a 3-phase delta connected heater bank to an electric power panel board is 1.____

   A. 2 B. 3 C. 4 D. 5

2. Of the following, the wire size that is MOST commonly used for branch lighting circuits in homes is _______ A.W.G. 2.____

   A. #12 B. #8 C. #6 D. #4

3. When installing electrical circuits, the tool that should be used to pull wire through a conduit is a 3.____

   A. mandrel
   B. snake
   C. rod
   D. pulling iron

4. Of the following AC voltages, the LOWEST voltage that a neon test lamp can detect is _______ volts. 4.____

   A. 6 B. 12 C. 80 D. 120

5. Of the following, the BEST procedure to use when storing tools that are subject to rusting is to 5.____

   A. apply a thin coating of soap onto the tools
   B. apply a light coating of oil to the tools
   C. wrap the tools in clean cheesecloth
   D. place the tools in a covered container

6. If a 3 1/2 inch long nail is required to nail wood framing members together, the nail size to use should be 6.____

   A. 2d B. 4d C. 16d D. 60d

7. Of the four motors listed below, the one that can operate only on alternating current is a(n) _______ motor. 7.____

   A. series
   B. shunt
   C. compound
   D. induction

8. The sum of 1/3 + 2/5 + 5/6 is 8.____

   A. 1 17/30 B. 1 3/5 C. 1 15/24 D. 1 5/6

9. Of the following instruments, the one that should be used to measure the state of charge of a lead-acid storage battery is a(n) 9.____

   A. ammeter
   B. ohmmeter
   C. hydrometer
   D. thermometer

10. If three 1 1/2 volt dry cell batteries are wired in series, the TOTAL voltage provided by the three batteries is _______ volts. 10.__

A. 1.5 B. 3 C. 4.5 D. 6.0

11. Taking into account time and one-half payment for time over 40 hours of work, the gross pay of an employee who works 43 hours in a week at a rate of pay of $10.68 per hour is 11.__

A. $427.20 B. $459.24 C. $475.26 D. $491.28

12. The sum of 0.365 + 3.941 + 10.676 + 0.784 is 12.__

A. 13.766 B. 15.666 C. 15.756 D. 15.766

13. In order to transmit mechanical power between two rotating shafts at right angles to each other, two gears are used. Of the following, the type of gears that should be used are _______ gears. 13.__

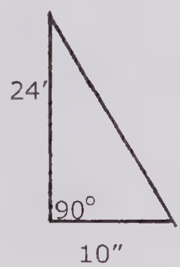
A. herringbone
B. spur
C. bevel
D. rack and pinion

14. To properly ground the service electrical equipment in a building, a ground connection should be made to _______ the building. 14.__

A. the waste or soil line leaving
B. the vent line going to the exterior of
C. any steel beam in
D. the cold water line entering

15. The area of the triangle shown at the right is _______ square inches. 15.__

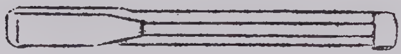
A. 120
B. 240
C. 360
D. 480

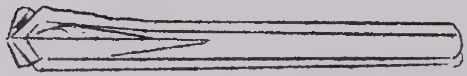


Questions 16-25.

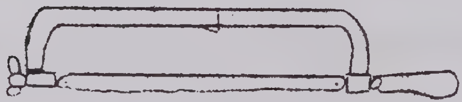
DIRECTIONS: Questions 16 through 25 are to be answered on the basis of the tools shown on the next page. The tools are not shown to scale. Each tool is shown with an identifying number alongside it.

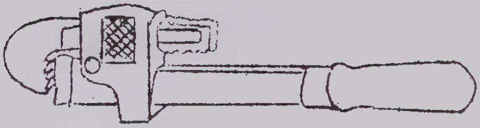
1. 

2. 

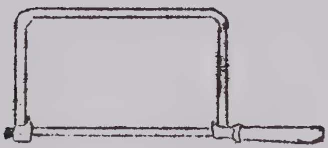
3. 

4. 

5. 

6. 

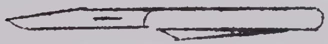
7. 

8. 

9. 

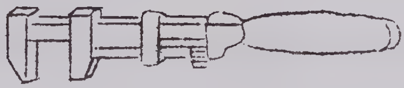
10. 

 11.

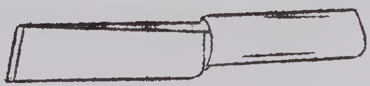
 12.

 13.

 14.

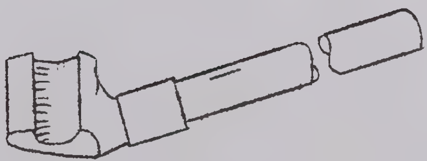
 15.

 16.

 17.

 18.

 19.

 20.

16. The tool that should be used for cutting thin wall steel conduit is Number 16.____

A. 5 B. 8 C. 10 D. 16

17. The tool that should be used for cutting a 1 7/8 inch diameter hole in a wood joist is Number 17.____

A. 3 B. 9 C. 14 D. 19

18. The tool that should be used for soldering splices in electrical wire is Number 18.____

A. 3 B. 7 C. 13 D. 14

19. After cutting off a piece of 3/4 inch diameter electrical conduit, the tool that should be used for removing a burr from the inside of the conduit is Number 19.____

A. 9 B. 11 C. 12 D. 14

20. The tool that should be used for turning a coupling onto a threaded conduit is Number 20.____

A. 6 B. 11 C. 15 D. 16

21. The tool that should be used for cutting wood lathing in plaster walls is Number 21.____

A. 5 B. 7 C. 10 D. 12

22. The tool that should be used for drilling a 3/8 inch diameter hole in a steel beam is Number 22.____

A. 1 B. 2 C. 3 D. 9

23. Of the following, the BEST tool to use for stripping insulation from electrical hook-up wire is Number 23.____

A. 11 B. 12 C. 15 D. 20

24. The tool that should be used for bending an electrical wire around a terminal post is Number 24.____

A. 4 B. 11 C. 15 D. 16

25. The tool that should be used for cutting electrical hookup wire is Number 25.____

A. 5 B. 12 C. 16 D. 17

KEY (CORRECT ANSWERS)

1.	B	11.	C
2.	A	12.	D
3.	B	13.	C
4.	C	14.	D
5.	B	15.	A
6.	C	16.	A
7.	D	17.	D
8.	A	18.	D
9.	C	19.	A
10.	C	20.	A

21.	C
22.	A
23.	B
24.	B
25.	C

TEST 3

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. An electric circuit has current flowing through it. The panel board switch feeding the circuit is opened, causing arcing across the switch contacts. Generally, this arcing is caused by 1.___

   A. a lack of energy storage in the circuit
   B. electrical energy stored by a capacitor
   C. electrical energy stored by a resistor
   D. magnetic energy induced by an inductance

2. MOST filter capacitors in radios have a capacity rating given in 2.___

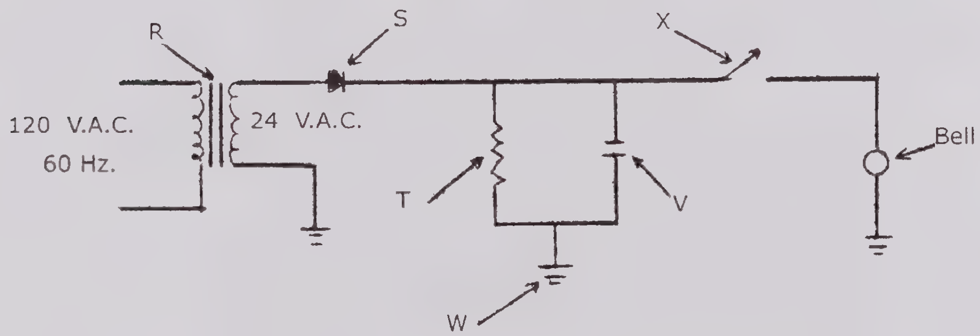
   A. microvolts B. milliamps
   C. millihenries D. microfarads

3. Of the following, the electrical wire size that is COMMONLY used for telephone circuits is _______ A.W.G. 3.___

   A. #6 B. #10 C. #12 D. #22

Questions 4-9.

DIRECTIONS: Questions 4 through 9 are to be answered on the basis of the electrical circuit diagram shown below, where letters are used to identify various circuit components.



4. The device indicated by the letter R is a 4.___

   A. capacitor B. converter
   C. resistor D. transformer

5. The device indicated by the letter S is a 5.___

   A. transistor B. diode
   C. thermistor D. directional relay

6. The devices indicated by the letters T and V are used together to ______ components of the secondary current. 6.____

A. reduce the AC
B. reduce the DC
C. transform the AC
D. invert the AC

7. The letter W points to a standard electrical symbol for a 7.____

A. wire
B. ground
C. terminal
D. lightning arrestor

8. Closing switch X will apply the following type of voltage to the bell: 8.____

A. 60 Hz. AC
B. DC
C. pulsating AC
D. 120 Hz. AC

9. The circuit shown contains a ______ rectifier. 9.____

A. mercury-arc
B. full-wave
C. bridge
D. half-wave

10. A bolt specified as 1/4-28 means the following: 10.____
The

A. bolt is 1/4 inch in diameter and has 28 threads per inch
B. bolt is 1/4 inch in diameter and is 2.8 inches long
C. bolt is 1/4 inch long and has 28 threads
D. threaded portion of the bolt is 1/4 inch long and has 28 threads per inch

11. When cutting 0.045-inch thickness sheet metal, it is BEST to use a hacksaw blade that has ______ teeth per inch. 11.____

A. 7
B. 12
C. 18
D. 32

12. To accurately tighten a bolt to 28 foot-pounds, it is BEST to use a(n) ______ wrench. 12.____

A. pipe
B. open end
C. box
D. torque

13. When bending a 2-inch diameter conduit, the CORRECT tool to use is a 13.____

A. hickey
B. pipe wrench
C. hydraulic bender
D. stock and die

14. When soldering two #20 A.W.G. copper wires together to form a splice, the solder that SHOULD be used is ______ solder. 14.____

A. acid-core
B. solid-core
C. rosin-core
D. liquid

15. A bathroom heating unit draws 10 amperes at 115 volts.
The hot resistance of the heating unit should be ______ ohms. 15.____

A. .08
B. 8
C. 11.5
D. 1150

16. Of the following materials, the one that is NOT suitable as an electrical insulator is 16.____

A. glass
B. mica
C. rubber
D. platinum

17. An air conditioning unit is rated at 1000 watts. The unit is run for 10 hours per day, five days per week.
If the cost for electrical energy is 5 cents per kilowatt-hour, the weekly cost for electricity should be 17.____

A. 25¢ B. 50¢ C. $2.50 D. $25.00

18. If a fuse is protecting the circuit of a 15 ohm electric heater and it is designed to blow out at a current exceeding 10 amperes, the MAXIMUM voltage from among the following that should be applied across the terminals of the heater is ______ volts. 18.____

A. 110 B. 120 C. 160 D. 600

19. Before opening a pneumatic hose connection, it is important to remove pressure from the hose line PRIMARILY to avoid 19.____

A. losing air
B. personal injury
C. damage to the hose connection
D. a build-up of pressure in the air compressor

20. If the scale on a shop drawing is 1/4 inch to the foot, then a part which measures 3 3/8 inches long on the drawing has an ACTUAL length of ______ feet ______ inches. 20.____

A. 12; 6 B. 13; 6 C. 13; 9 D. 14; 9

21. The function that is USUALLY performed by a motor controller is to 21.____

A. start and stop a motor
B. protect a motor from a short circuit
C. prevent bearing failure of a motor
D. control the brush wear in a motor

22. Of the following galvanized sheet metal electrical outlet boxes, the one that is NOT a commonly used size is the ______ box. 22.____

A. 4" square
B. 4" octagonal
C. 4" x 2 1/8"
D. 4" x 1"

23. When soldering a transistor into a circuit, it is MOST important to protect the transistor from 23.____

A. the application of an excess of rosin flux
B. excessive heat
C. the application of an excess of solder
D. too much pressure

24. When installing BX type cable, it is important to protect the wires in the cable from the cut ends of the armored sheath.
The APPROVED method of providing this protection is to 24.____

A. use a fiber or plastic insulating bushing
B. file the cut ends of the sheath smooth
C. use a connector where the cable enters a junction box
D. tie the wires into an Underwriter's knot

25. While lifting a heavy piece of equipment off the floor, a person should NOT 25.____

A. twist his body
B. grasp it firmly
C. maintain a solid footing on the ground
D. bend his knees

26. It is important that metal cabinets and panels that house electrical equipment should be grounded PRIMARILY in order to 26.____

A. prevent short circuits from occurring
B. keep all circuits at ground potential
C. minimize shock hazards
D. reduce the effects of electrolytic corrosion

27. A foreman explains a technical procedure to a new employee. If the employee does not understand the instructions he has received, it would be BEST if he were to 27.____

A. follow the procedure as best he could
B. ask the foreman to explain it to him again
C. avoid following the procedure
D. ask the foreman to give him other work

28. Of the following, the BEST connectors to use when mounting an electrical panel box directly onto a concrete wall are 28.____

A. threaded studs
B. machine screws
C. lag screws
D. expansion bolts

29. Of the following, the BEST instrument to use to measure the small gap between relay contacts is 29.____

A. a micrometer
B. a feeler gage
C. inside calipers
D. a plug gage

30. A POSSIBLE result of mounting a 40 ampere fuse in a fuse box for a circuit requiring a 20 ampere fuse is that the 40 ampere fuse may 30.____

A. provide twice as much protection to the circuit from overloads
B. blow more easily than the smaller fuse due to an overload
C. cause serious damage to the circuit from an overload
D. reduce power consumption in the circuit

KEY (CORRECT ANSWERS)

1.	D	16.	D
2.	D	17.	C
3.	D	18.	B
4.	D	19.	B
5.	B	20.	B
6.	A	21.	A
7.	B	22.	D
8.	B	23.	B
9.	D	24.	A
10.	A	25.	A
11.	D	26.	C
12.	D	27.	B
13.	C	28.	D
14.	C	29.	B
15.	C	30.	C

EXAMINATION SECTION
TEST 1

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. Reversing the current flow through a coil 1.____

   A. reduces the amount of flux produced
   B. reverses its two-pole field
   C. reduces power consumed
   D. reduces eddy currents

2. The unit of magnetic flux is 2.____

   A. ampere-turn
   B. gilbert
   C. intensity
   D. maxwell

3. Flux in a magnetic circuit compares in an electrical circuit with 3.____

   A. voltage
   B. current
   C. resistance
   D. opposition

4. If a compass is placed in the vicinity of a conductor carrying d.c., the needle aligns itself 4.____

   A. in the direction of current flow in the conductor
   B. at right angles to the conductor
   C. in the general direction of the north pole
   D. in the general direction of the south pole

5. The left-hand rule for coils states: Grasping the 5.____

   A. coil with the left hand, with fingers pointing in the direction of the magnetic field, the middle finger will point to the north pole
   B. coil with the left hand, thumb pointing in the direction of the conductor movement, the fingers will point in the direction of the magnetic field
   C. conductor with the left hand, fingers pointing in the direction of the north pole, the thumb will indicate current flow
   D. coil in the left hand, fingers wrapped around in the direction of electron flow, the thumb will point towards north pole

6. The word *permeability* indicates the 6.____

   A. amount of reluctance of one centimeter-cube of air
   B. number of turns of an air core
   C. ability of a substance to conduct magnetic lines of force
   D. m.m.f. required to produce one gilbert

7. If an iron core is inserted part way into a coil and current is applied to the coil, the core will be drawn into the coil in an effort to 7.____

   A. increase reluctance of the magnetic circuit
   B. decrease the length of the magnetic circuit

C. reduce the permeability of the circuit
D. increase the residual effect

8. Current flow in a straight conductor produces 8.___

A. hysteresis
B. magnetic lines of force
C. a north pole
D. permeability

9. The induction of a coil depends upon the 9.___

A. number of turns, current flow, type of core material, and ratio of coil's length to its width
B. current, flux, and core material
C. direction of rotation, flux, and speed
D. permeability, reluctance, gausses, and maxwells

10. The ability of a magnetic substance to hold its magnetism after the magnetizing force has been removed is 10.___

A. residual
B. retentivity
C. hysteresis
D. permeability

11. The solenoid and plunger type of magnet is employed in various forms to control 11.___

A. electrical equipment
B. hysteresis losses
C. permeability
D. all of the above

12. When using the left-hand rule for a conductor, 12.___

A. grasp the conductor with fingers pointing in the direction of current flow and thumb will indicate direction of field
B. the compass will point in the direction of current flow and fingers will indicate direction of magnetic field
C. grasp the conductor with the thumb extended in the direction of electron flow, the fingers will point in the direction of the magnetic lines of force
D. reverse the current flow and thumb will point in the direction of the magnetic field

13. The magnetic circuit is determined by 13.___

A. lines of force leaving the south pole and entering the north pole externally
B. permeability to current and the north pole
C. maxwells to length in centimeters and the south pole
D. the complete path taken by magnetic lines leaving the north pole, and returning to the north pole

14. In what material is retentivity MOST apparent? 14.___

A. Hard steel
B. Soft iron
C. Copper
D. Wood

15. The armature type of electromagnet 15.___

A. has a movable iron bar in its magnetic circuit
B. uses a permanent magnet core
C. has a hard steel core and a pivoted bar of copper
D. has a movable iron core

16. When two parallel conductors carrying current in the same direction are placed side by side, the fields produced by both 16.____

A. cancel each other's field
B. push each other apart
C. form a north pole
D. encircle each other, drawing the conductors together

17. The equivalent Ohm's law formula for magnetic circuits is 17.____

A. $I = \frac{e}{r}$ B. $R = \frac{I}{E}$ C. $\Phi = \frac{E}{R}$ D. $P = \frac{I}{E}$

18. Which of the following materials incurs low hysteresis loss when used for transformer cores and similar applications? 18.____

A. Hard steel
B. Annealed steel
C. Soft iron
D. Cast steel

19. The magnetic field around a current-carrying wire 19.____

A. is parallel to the current flow in the conductor
B. exists at all points along its length
C. exists only at the beginning of electron movement
D. moves in the direction of current flow

20. Direct current flows through a coil of wire which has an iron core. When the iron core is removed and all other factors remain unchanged, the total number of lines of force through the coil will change because 20.____

A. changing the core material affects m.m.f.
B. permeance has been increased
C. reluctance has been increased
D. the permeability of the magnetic circuit has been increased

---

KEY (CORRECT ANSWERS)

1.	B	11.	A
2.	D	12.	C
3.	B	13.	D
4.	B	14.	A
5.	D	15.	A
6.	C	16.	D
7.	B	17.	C
8.	B	18.	C
9.	A	19.	B
10.	B	20.	C

TEST 2

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. In formula form, angular velocity as applied to voltage or current is 1.___

   A. 2ω B. $2\pi\omega$ C. $2\pi F$ D. 2F

2. How much larger is the maximum voltage value than the effective voltage value? 2.___

   A. 1.414 B. 1.111 C. 0.707 D. 0.637

3. How many radians are in a complete circle? 3.___

   A. 0.707 B. 1.11 C. 3.14 D. 6.28

4. Magnitude of a vector is denoted by the 4.___

   A. time axis
   B. length of the line
   C. length of the line, drawn to scale
   D. length of the time axis, drawn to scale

5. Which of the following BEST defines a cycle? 5.___

   A. One alternation B. Two alternations
   C. Three alternations D. Four alternations

6. The MOST important value associated with sine waves of voltage or current are 6.___

   A. instantaneous B. maximum
   C. average D. all of the above

7. The MAXIMUM value of a single sine wave of a-c voltage is 141.4 volts. What is the effective value? _______ volts. 7.___

   A. 63.7 B. 70.7 C. 99.97 D. 141.4

8. Direction of a simple vector 8.___

   A. cannot be determined
   B. will indicate the reference point
   C. is indicated by an arrow at one end of the line
   D. is indicated by the magnitude

9. Frequency as applied to alternating current or voltage is the number of _______ per second of time. 9.___

   A. r.p.m. B. cycles
   C. poles D. volts generated

10. The effective value of an a-c voltage or current of sine waveform is defined in terms of the equivalent d.c. "_______ effect". 10._____

A. voltage
B. current
C. heating
D. cooling

11. The average value of a single sine wave of a-c current is 63.7 amps. What is the r.m.s. value? _______ amps. 11._____

A. 63.7
B. 70.7
C. 141.4
D. 156.95

12. The instantaneous value of induced voltage of a single-phase generator 12._____

A. will never be zero
B. depends on the sine of the angle
C. will always be the same
D. depends on the cosine of the angle

13. The period of a-c voltage of sine waveform is the time required for one complete 13._____

A. r.p.m.
B. alternation
C. cycle
D. degree

14. The "root-mean-square" value is also known as the _______ value. 14._____

A. average
B. peak
C. instantaneous
D. effective

15. Two voltages of the same frequency "120 cycles per second" have their positive maximum values displaced by 90°. 15._____
What is the time difference between the phases? _______ sec.

A. 0.00208
B. 0.00416
C. 0.02080
D. 0.04160

16. Positive rotation of a vector is 16._____

A. clockwise
B. counterclockwise
C. either clockwise or counterclockwise
D. neither clockwise nor counterclockwise

17. The effective generated voltage of a single-phase a-c generator may be obtained by the formula 17._____

A. $E = 1.111\ \Phi\ fD10^{-8}$
B. $E = 2.22\ \Phi\ fN^{-6}$
C. $E = 1.111\ \Phi\ FD^{-6}$
D. $E = 2.22\ \Phi\ fN^{-8}$

18. Most a-c voltmeters and ammeters are calibrated in _______ values. 18._____

A. r.m.s.
B. average
C. peaks
D. instantaneous

19. A radian is ALWAYS equal to 19._____

A. the circumference of the circle
B. the radius of the circle
C. π
D. 60 degrees

20. Angular velocity is symbolized by the Greek letter 20.__

A. gamma γ B. mu μ C. omega ω D. beta β

21. If an active conductor's length is doubled, the 21.__

A. pole length is cut in half
B. flux per pole is cut in half
C. generated voltage is doubled
D. generated voltage is tripled

22. The "form factor" in most cases refers to the ratio of 22.__

A. average value to maximum value
B. instantaneous value to maximum value
C. r.m.s. value to effective value
D. r.m.s. value to average value

23. Conductor size in an a-c circuit is based on ______ current. 23.__

A. instantaneous B. maximum
C. average D. effective

24. The term "angular velocity," as applied to electricity, refers to the number of 24.__

A. radians per second a voltage vector rotates
B. radians per minute a voltage vector rotates
C. degrees averaged together
D. degrees subtracted from the radians

25. Vectors indicate 25.__

A. direction
B. magnitude
C. time, direction, and magnitude
D. magnitude and direction

KEY (CORRECT ANSWERS)

1.	C	11.	B
2.	A	12.	B
3.	D	13.	C
4.	C	14.	D
5.	B	15.	B
6.	D	16.	B
7.	C	17.	D
8.	C	18.	A
9.	B	19.	B
10.	C	20.	C

21.	C
22.	D
23.	D
24.	A
25.	D

TEST 3

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. Inductance is the property of an electric circuit that 1.___

   A. opposes any change in the applied voltage through that circuit
   B. opposes any change in the current through that circuit
   C. aids any change in the applied voltage through that circuit
   D. aids any change in the current through that circuit

2. A coil has a resistance of 22 ohms, and, in 0.1 second after the switch is closed, the current has reached 63.2% of its final value. 2.___
   The value of inductance (L) is ______ henries.

   A. 0.22 B. 0.44 C. 2.20 D. 4.40

3. When a capacitor's counter e.m.f. has risen to equal the battery voltage, the current is 3.___

   A. maximum in the circuit
   B. at 63.2% of its maximum Ohm's law value in the circuit
   C. zero in the circuit
   D. at 36.8% of its maximum Ohm's law value in the circuit

4. The total capacitance of two 100-microfarad capacitors connected in series is _______ microfarads. 4.___

   A. 25 B. 50 C. 100 D. 200

5. When the magnetic field is collapsing, the induced e.m.f. 5.___

   A. aids and tends to prolong the impressed current
   B. opposes the impressed current
   C. has no effect upon the impressed current
   D. causes the impressed current to go immediately to zero

6. To increase the time required for the current to reach its maximum Ohm's law value in a series resistance and inductance circuit, it is necessary to 6.___

   A. increase the resistance
   B. decrease the resistance
   C. decrease the inductance
   D. increase the applied voltage

7. In a simple capacitor, the plate area is 2 square inches, the dielectric material is mica, and the distance between the plates is 0.01 inch. To increase the capacitance, 7.___

   A. increase the distance between the plates
   B. change dielectric material from mica to paraffin paper
   C. decrease the plate area
   D. change dielectric material from mica to flint glass

8. What is the total capacitance of two 200-microfarad capacitors connected in series with each other and both in parallel with a 50-microfarad capacitor? _______ microfarads. 8._____

A. 50 B. 250 C. 100 D. 150

9. The unit of inductance is the 9._____

A. ohm B. farad C. henry D. coulomb

10. The coefficient of coupling of two coils is 10._____

A. increased by turning one coil axis at right angles to the other coil axis
B. greatly increased with the addition of a soft iron core
C. generally higher in an air core circuit than in an iron core circuit
D. almost unity on a diamagnetic core

11. Factors that determine the capacitance of parallel-electrode capacitors are 11._____

A. area of the plates and the type of dielectric
B. thickness of the plates, type and thickness of the dielectric
C. type and thickness of the dielectric and the plate area
D. thickness of the dielectric, area of the plate, and the direction of the current flow

12. The time constant of a resistance-capacitance circuit is 12._____

A. the time required to discharge a capacitor to 36.8% of its final voltage
B. the time required to charge a capacitor to 36.8% of its maximum voltage
C. equal to the circuit capacitance divided by the circuit resistance
D. equal to the circuit resistance divided by the circuit capacitance

13. The voltage due to self-induction 13._____

A. can only occur when the conductor is wound in the form of a coil
B. is produced when the strength of the magnetic field changes
C. is produced by moving a conductor through a magnetic field
D. cannot occur in a direct-current circuit

14. If two coils are positioned with respect to each other so as to have unity coefficient of coupling and the inductance of coil A equals coil B, what is the mutual inductance between the two coils? 14._____

A. Equal to the inductance of coil A
B. One-half of the inductance of coil A
C. Double the inductance of coil A
D. Equal to the square root of the inductance of coil A

15. The capacitance of a capacitor is inversely proportional to the 15._____

A. frequency of the applied voltage
B. dielectric constant
C. active plate area
D. distance between the plates

16. A 40-microfarad capacitor in series with 2,000 ohms is connected to a 200-volt source. The time constant is _______ second. 16.___

A. 0.05 B. 0.08 C. 0.50 D. 0.80

17. To increase the inductance of a coil, 17.___

A. increase the permeability of the core material
B. increase the length of the coil
C. increase the magnitude of the current flow through the coil
D. decrease the cross-sectional area of the coil

18. What is the total inductance (L_t) of two coils connected in parallel when the coefficient of coupling is zero? 18.___

A. $L_t = L_1 + L_2$

B. $L_t = L_1$

C. $L_t = \frac{1}{L_1} + \frac{1}{L_2}$

D. $L_t = \frac{L_1 L_2}{L_1 + L_2}$

19. The charge that is stored in a capacitor depends upon 19.___

A. voltage divided by the capacitance
B. voltage multiplied by the capacitance
C. capacitance divided by the voltage
D. capacitance multiplied by the resistance

20. When selecting a capacitor for use in a circuit, its working voltage should be AT LEAST 20.___

A. 10% greater than the highest voltage to be applied to it
B. equal to the highest voltage to be applied to it
C. 30% greater than the highest voltage to be applied to it
D. 50% greater than the highest voltage to be applied to it

21. A battery, a switch, a resistor, and a coil are connected in series. What happens at the instant the switch is closed? The 21.___

A. voltage across the resistor is maximum
B. voltage across the coil is maximum
C. current in the circuit is maximum
D. voltage across the resistor and the coil are minimum

22. Capacitance is the property of an electric circuit that 22.___

A. opposes any change of current in the circuit
B. opposes any change of voltage in the circuit
C. is not affected by a change of voltage
D. aids any change of current in the circuit

23. When capacitors are connected in parallel, the resulting capacitance is the 23.____

A. sum of the individual capacitances
B. reciprocal of the sum of reciprocals of the individual capacitors
C. sum of the individual reciprocals of the capacitors
D. reciprocal of the sum of capacitances

24. The time constant of an inductive-resistive circuit is 24.____

A. that time required for a direct current to rise one-half of its maximum value
B. a method of determining how much current would flow at the end of one second
C. the product of the resistance and the inductance of a circuit
D. the time in seconds required for the current to rise to 63.2% of its final Ohm's law value

25. When capacitors are connected in series, the resulting capacitance is found by 25.____

A. a rule similar to that for combining parallel resistors
B. a rule similar to that for combining resistors in series
C. dividing the applied voltage by the total resistance of series circuit
D. multiplying the applied voltage by the total resistance of series circuit

---

KEY (CORRECT ANSWERS)

1.	B	11.	C
2.	C	12.	A
3.	C	13.	B
4.	B	14.	A
5.	A	15.	D
6.	B	16.	B
7.	D	17.	A
8.	D	18.	D
9.	C	19.	B
10.	B	20.	D

21. B
22. B
23. A
24. D
25. A

TEST 4

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. When frequency is increased in an inductive circuit, the current flow will 1.___

   A. increase because of greater inductive voltage
   B. increase because of less inductive voltage
   C. decrease because of greater inductive voltage
   D. decrease because of less inductive voltage

2. The unit of measurement for reactive power is the 2.___

   A. Volt Amp (VA)
   B. Volt Amp Wattage (VAW)
   C. Volt Amp Reactive (VAR)
   D. Volt Amp Kilo Watt (VAKW)

3. The prime factors that determine inductive reactance are 3.___

   A. frequency and current
   B. frequency and inducted voltage
   C. inductance and frequency
   D. inductance and voltage

4. What are the prime factors affecting capacitive reactance? 4.___

   A. Frequency and capacitance
   B. Frequency and inductance
   C. Frequency and resistance
   D. Frequency squared

5. The reaction of an inductor to any change in current is known as inductive 5.___

   A. reactance
   B. voltage
   C. current
   D. resistance

6. What two quantities comprise the total power of an a-c circuit? 6.___

   A. Apparent power and VARS
   B. True power and VARS
   C. True power and VAWS
   D. True power and power factor

7. Power factor is the 7.___

   A. percentage of apparent power expended in heat
   B. amount of apparent power in an a-c circuit
   C. amount of apparent power plus true power
   D. efficiency of a circuit expressed as an angle

8. The unit of measurement for inductive reactance is the 8.___

   A. ohm
   B. volt
   C. ampere
   D. henry

9. What is the power factor of a pure capacitive circuit? 9.____

A. 70.7% B. 86.6% C. 100% D. 0%

10. The self-induced voltage in a coil depends on the 10.____

A. voltage applied
B. inductive reactance
C. c.e.m.f.
D. current change in the coil

11. What is the path for current flow through a capacitor? 11.____

A. Does not actually flow through
B. From negative plate to positive plate
C. From positive plate to negative plate
D. From dielectric to plates

12. Power is described as the rate at which 12.____

A. work is being done
B. energy is being used
C. energy is being expended
D. all of the above are produced

13. What is the power characteristic of a positive inductive circuit? 13.____

A. Positive power is the largest.
B. Positive and negative power are equal.
C. Negative power is the largest.
D. Negative power is the smallest.

14. The vector sum of X_C and R in a series R-C circuit is the total 14.____

A. opposition to voltage in the circuit
B. capacitive reactance in the circuit
C. resistance in the circuit
D. opposition to current flow in the circuit

15. Self-induced voltage in an inductor will ALWAYS oppose 15.____

A. the applied voltage by 180 degrees
B. circuit current
C. the applied voltage by 90 degrees
D. the circuit current by 180 degrees

16. What is the value of apparent current flow in a capacitive circuit when it is FIRST energized? 16.____

A. No current flow in a capacitive circuit
B. Minimum
C. Maximum
D. Zero

17. What is the phase relationship between current and voltage in a resistive circuit? 17.___

A. 90^o phase difference
B. 0^o phase difference
C. Out of phase
D. Cannot be determined without numerical value of R

18. Voltage and current are considered to be out of phase with each other in a pure inductive circuit by what amount? Current 18.___

A. leads voltage by 90^o
B. lags voltage by 90^o
C. leads voltage by 180^o
D. lags voltage by 180^o

19. What is the phase relationship between current and voltage in a pure capacitive circuit? 19.___

A. No phase angle
B. Current lags voltage by 90^o
C. Voltage leads current by 90^o
D. Voltage lags current by 90^o

20. The phase angle between current and voltage in a circuit containing both resistive and inductive elements is 20.___

A. greater than 0^o but less than 90^o
B. a constant 45^o
C. 90^o at all times
D. 0^o because X_L and R are equal

21. In the formula for capacitive reactance, the symbol "C" represents capacitance in 21.___

A. farads
B. micromicrofarads
C. microfarads
D. ohms

22. What is the effect on capacitor voltage when frequency is increased? Voltage 22.___

A. increases
B. decreases
C. not affected
D. is minimum

23. What is impedance? 23.___

A. Opposition to current flow in an a-c circuit created by resistance and reactances
B. Resistance of an a-c circuit
C. Vector sum of voltage drops in an a-c circuit
D. Current divided by voltage in an a-c circuit

24. When voltages are out of phase, the total voltage can be found by adding 24.___

A. arithmetically
B. vectorially
C. peak value
D. average values

25. The number of radians per second traversed by an alternating-voltage vector is CLOSELY related to its 25.____

A. current sine wave
B. voltage sine wave
C. frequency
D. none of the above

KEY (CORRECT ANSWERS)

1. C
2. C
3. C
4. A
5. A
6. B
7. A
8. A
9. D
10. D
11. A
12. D
13. B
14. D
15. A
16. C
17. B
18. B
19. D
20. A
21. A
22. B
23. A
24. B
25. C

TEST 5

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. When resistive, inductive, and capacitive elements are connected in series, 1.___

   A. they lose their individual characteristics
   B. their individual characteristics remain unchanged
   C. the inductance component is always the largest
   D. the capacitive component is always the largest

2. In a circuit containing both X_C and X_L, if the difference between X_C and X_L increases, the total 2.___

   A. impedance decreases
   B. impedance increases
   C. impedance remains the same
   D. resistance increases

3. In a 60-cycle a-c circuit, with an inductor of 0.053 microhenry and a resistance of 50 ohms connected in series, the impedance would be _______ ohms. 3.___

   A. 539 B. 5.39 C. 53.9 D. 19.97

4. The effective resistance of a circuit may be defined as the ratio of the 4.___

   A. true power absorbed by the circuit to the square of the effective current flowing
   B. apparent power absorbed by the circuit to the square of the effective current flowing
   C. true power absorbed by the circuit to the square of the total resistance in the circuit
   D. apparent power absorbed by the circuit to the square of the total resistance in the circuit

5. In a series circuit, when X_C and X_L are equal, 5.___

   A. line voltage leads line current by an unknown $\angle\theta$
   B. line current leads line voltage by an unknown $\angle\theta$
   C. total impedance is minimum
   D. total impedance is maximum

6. To find true power, use the formula 6.___

   A. T.P. = E x 1
   B. T.P. = E x 1 x cos $\angle\theta$
   C. T.P. = $E^2 \div \cos \angle\theta$
   D. T.P. = E x 1 x sin $\angle\theta$

7. A low-loss inductor has a low 7.___

   A. X_L at high frequencies
   B. current at low frequencies
   C. inductance
   D. resistance

8. The MOST inefficient method of voltage reduction, from the standpoint of power loss, is a(n) 8.____

   A. capacitor in series with the load
   B. inductor in series with the load
   C. capacitor and an inductor in series with the load
   D. resistor in series with the load

9. The formula for finding the loss factor of a capacitor is the dielectric constant 9.____

   A. times the power factor
   B. divided by the power factor
   C. times the apparent power
   D. times the true power

10. A phase difference between E and I causes 10.____

   A. true power to increase
   B. apparent power to increase
   C. true power to decrease
   D. apparent power to decrease

11. The energy component of a current flowing in an R-L circuit is the current flowing through the 11.____

   A. inductor and resistor
   B. inductor
   C. resistor
   D. power source

12. Corona loss is the result of 12.____

   A. emission of electrons from the surface of a conductor
   B. electron collision inside a conductor
   C. overheating a high-frequency conductor
   D. none of the above

13. To find total true power in a parallel circuit, first find the true power in each branch and then 13.____

   A. add the power in all branches arithmetically
   B. add the power in all branches using the parallelogram method
   C. multiply the voltage times the current
   D. multiply the square of the current times the resistance

14. The hypotenuse of the power triangle represents 14.____

   A. true power
   B. VARS
   C. apparent power
   D. none of the above

15. To find a circuit's power factor in percent, use the formula 15.____

   A. $P.F. = \frac{AP}{TP} X 100$
   B. $P.F. = \cos \angle\theta$
   C. P.F. = angle in degrees x 100
   D. $P.F. = \frac{E \times I \times \cos \angle\theta}{E \times I} \times 100$

16. Corona loss can be held to a satisfactory low value by 16.

A. avoiding sharp points, bends, and turns
B. using low voltages
C. using large diameter conductors
D. all of the above

17. In a parallel circuit with a lagging power factor, to improve the power factor, 17.

A. increase the inductance
B. put an inductor in parallel with the rest of the circuit
C. put a capacitor in parallel with the rest of the circuit
D. decrease the resistance

18. The non-energy component of an a-e circuit is 18.

A. true power
B. reactive power
C. apparent power
D. none of the above

19. The formula for computing R - L - C in series is 19.

A. $Z = R_T + X_L + X_C$
B. $Z = R + X_L - X_C$
C. $Z^2 = R^2 + (X_L^2 - X_C^2)$
D. $Z = R^2 + (X_L^2 - X_C^2)$

20. One radian is equal to 20.

A. $\frac{180}{2\pi}$
B. 2π
C. 1.414
D. $\frac{360}{2\pi}$

21. Skin effect describes the tendency of 21.

A. d-c conductors to carry the circuit current on their surfaces
B. a-c conductors to carry the circuit current on their surfaces
C. both a-c and d-c conductors to carry the circuit current on their surfaces
D. none of the above

22. The current in an a-c parallel circuit varies 22.

A. inversely with the cos $\angle\theta$
B. directly with the cos $\angle\theta$
C. inversely with the sine $\angle\theta$
D. directly with the sine $\angle\theta$

23. In a circuit containing X_C and X_L, if X_C is larger, 23.____

A. the voltage would lead the current
B. the current would lead the voltage
C. there would be no phase difference
D. true power is maximum

24. The effective resistance of a capacitor dissipated in heat in the 24.____

A. positive capacitor plate
B. negative capacitor plate
C. dielectric
D. leads connecting the capacitor in the circuit

25. When loops of wire are formed into a coil and current is passed through this coil, 25.____

A. the result is a permanent magnet
B. each turn will cancel the magnetic field of each adjacent turn
C. the magnetic field of each turn of wire links with the fields of adjacent turns
D. permeability decreases to minimum

KEY (CORRECT ANSWERS)

1. B
2. B
3. C
4. A
5. C

6. B
7. D
8. D
9. A
10. C

11. C
12. A
13. A
14. C
15. D

16. D
17. C
18. B
19. C
20. D

21. B
22. A
23. B
24. C
25. C

TEST 6

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. In a D'Arsonval type meter, the PRIMARY purpose of the iron core is to 1.____

   A. dampen coil movement
   B. concentrate the flux between the core and the pole piece
   C. concentrate the flux between the core and the hairsprings
   D. weaken the flux between the core and the pole piece

2. The D'Arsonval movement operates on the principle of 2.____

   A. mutual induction
   B. repulsion
   C. magnetic repulsion and attraction
   D. magnetic attraction

3. In order to measure large currents with the D'Arsonval ammeter, 3.____

   A. the meter must be made more rugged
   B. an increased number of turns must be put on the moving coil
   C. shunts are used
   D. the pointer must be lengthened

4. The PRIMARY purpose of the megger is to measure 4.____

   A. milliohms B. kilohms
   C. megohms D. microhms

5. A moving iron-vane meter works on the principle of 5.____

   A. induction B. repulsion
   C. conduction D. attraction

6. When hairsprings are used in a D'Arsonval type meter, they 6.____

   A. serve as conductors
   B. are wound oppositely and provide restoring forces
   C. are attached to the ends of the bobbin
   D. produce all of the above

7. The metal ribbons attached to the moving coil in the galvanometer have no force on them when the 7.____

   A. north pole of the moving coil is close to the south pole of the horseshoe magnet
   B. north pole of the moving coil is as close as possible to the north pole of the horseshoe magnet
   C. north pole of the moving coil is 90° from the north pole of the horseshoe magnet
   D. south pole of the moving coil is as close as possible to the south pole of the horseshoe magnet

8. When shunts are used with an ammeter, they 8.____

A. must be located within the case
B. must be located outside the case
C. may be located either inside or outside the case
D. reduce the accuracy of the movement

9. The power supply for a megger comes from 9.____

A. two flashlight batteries
B. a hand-driven generator
C. any 115 v. wall plug
D. the aircraft battery

10. The iron-vane meter can be used on 10.____

A. a.c. only
B. a.c. and d.c.
C. d.c. only
D. rectified a.c.

11. The Weston meter uses the principle of operation of the 11.____

A. D'Arsonval galvanometer
B. Thompson incline coil
C. iron vane
D. V.T.V.M.

12. Current-measuring instruments MUST always be connected in 12.____

A. parallel with a circuit
B. series with a circuit
C. series-parallel with a circuit
D. delta with the shunt

13. If the pointer fails to come back to zero when the megger is not in use, 13.____

A. the megger is out of calibration
B. this is normal operation
C. the hairsprings are burned out
D. the pointer is stuck

14. When using ammeters, 14.____

A. reverse polarity must be used
B. + or - polarity can be used
C. polarity should be observed
D. regardless of polarity, the instrument cannot be damaged because it is grounded

15. For measuring resistances of multimillions of ohms, use a(n) 15.____

A. TS 297 multimeter
B. ohmmeter with high scales
C. megger
D. combustion volt ammeter

16. Dampening is accomplished in the iron-vane meter by 16.____

A. hairsprings
B. the hermetically sealed case
C. an aluminum bobbin
D. an aluminum vane

17. Balance springs on each end of the shaft of the Weston ammeter 17.___

A. are used to carry current to the moving coil
B. are not balanced due to temperature change
C. provide a turning force for the pointer
D. are factory adjusted and must not be re-adjusted

18. The electrodynamometer-type meter employs 18.___

A. two permanent magnets
B. one permanent magnet and one electromagnet
C. two fixed coils and one movable permanent magnet
D. none of the above

19. With the ohmmeter setting on R x 1, it takes 0.01 ma. to deflect the pointer to half scale. If the meter were set on R x 100, how much would it take to deflect the pointer to half scale? _______ ma. 19.___

A. 0.1 B. 0.01 C. 0.001 D. 1.0

20. Electrodynamometer-type meters 20.___

A. never utilize shunts
B. utilize four coils, all of which are movable
C. are seldom used in the laboratory because they are not accurate enough
D. are not as sensitive as the D'Arsonval meter

21. Meggers provided aboard ships are usually rated at _______ volts. 21.___

A. 250 B. 500 C. 750 D. 1,000

22. The voltage developed in the thermocouple-type meter depends on the 22.___

A. material of which the wires are made
B. direction of current flow
C. frequency of the heater voltage
D. type of meter movement

23. A multimeter contains a 23.___

A. voltmeter and wattmeter
B. voltmeter and frequency meter
C. voltmeter, ohmmeter, and milliammeter
D. voltmeter, ammeter, and ohmmeter

24. In the iron-vane power factor meter, the spiral springs 24.___

A. are eliminated
B. return the pointer to zero
C. oppose torque
D. carry current to coils A and B

25. Instruments that are used to measure voltage and current regardless of circuit ratings are 25.___

A. instrument transformers
B. autotransformers
C. electrodynamometers
D. D'Arsonvals

KEY (CORRECT ANSWERS)

1. B
2. C
3. C
4. C
5. B
6. D
7. B
8. C
9. B
10. B
11. A
12. B
13. B
14. C
15. C
16. D
17. A
18. D
19. B
20. D
21. B
22. A
23. C
24. A
25. A

EXAMINATION SECTION
TEST 1

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. A shunt motor having an armature whose resistance is 0.5 ohm is attached to a 120 volt supply. The armature current at full speed is 10 amperes. 1.____
The back EMF, in volts, will be

A. 5 B. 10 C. 115 D. 125

2. An electron stream sent horizontally through a magnetic field whose lines of force are horizontal and at right angles to the electron stream will 2.____

A. curve in a horizontal plane
B. curve in a vertical plane
C. curve in a plane neither horizontal nor vertical
D. pass through without curving

3. In a series wound DC electrical generator, the current in the line is 3.____

A. the same as the field current
B. half the current through either brush
C. twice the current through either brush
D. independent of the field current

4. The MOST economical 0.1 mfd condenser to be used without danger of shorting on a 250-volt AC line is one whose DC working voltage is rated at 4.____

A. 250 B. 300 C. 400 D. 600

5. As the frequency of an alternating EMF in a given circuit increases, the current in the circuit at first increases then decreases. 5.____
The circuit contains

A. only capacitative reactance
B. only inductive reactance
C. both capacitative and inductive reactance
D. a constant impedance

6. A storage cell is connected in series with a resistance of 0.3 ohms. 6.____
If the resistance of the cell is 0.2 ohms and its EMF is 2.5 volts, the current, in amperes, in the circuit is

A. 1/5 B. 5 C. 7.5 D. 12.5

7. A condenser of capacitance C is charged to a potential V by a quantity of charge Q. 7.____
The energy stored in the condenser is

A. 1/2CV B. $1/2CV^2$ C. CV D. $1/2CQ^2$

8. In the transistor, the impurities in the crystals that are GENERALLY used are 8.___

A. osmium and cerium
B. silicon and germanium
C. cadmium and strontium
D. boron and phosphorus

9. A galvanometer having an armature coil with a resistance of 10 ohms requires .01 amperes for a full-scale deflection. 9.___
To convert this galvanometer to a voltmeter which will give a full-scale deflection when the voltage is 120 volts, a coil in series must be added that will have a resistance, in ohms, of

A. 120
B. 1200
C. 1210
D. 11,990

10. A given length of copper wire has a resistance of 16 ohms. An equal length of copper wire having 4 times the diameter of the given wire will have a resistance of _______ ohm(s). 10.___

A. 1
B. 4
C. 16
D. 64

11. A battery has an open circuit voltage of 20 volts and an internal resistance of 0.25 ohm. When it delivers a current of 10 amperes, the terminal voltage will be 11.___

A. 15
B. 17.5
C. 18
D. 20

12. The energy converted into heat during a cycle of a hysteresis loop was formulated by 12.___

A. Steinmetz
B. Edison
C. Hertz
D. Maxwell

13. Assume that the movable coil of a D'Arsonval type of voltmeter that has a resistance of 300 ohms and a current of 0.02 ampere will give a full-scale reading. 13.___
The series resistance, in ohms, needed to construct a voltmeter with a full scale of 150 volts is

A. 7200
B. 8100
C. 7800
D. 7500

14. An alternating voltage is supplied to a circuit consisting of an incandescent lamp and a coil of many turns. 14.___
The current in the circuit

A. lags behind the voltage
B. leads the voltage
C. is in phase with the voltage
D. is rectified into direct current

15. A series circuit with resistance of 40 ohms, inductive reactance of 75 ohms, and capacitive reactance of 45 ohms is connected to a 150 volt AC source. 15.___
The impedance of the circuit is, in ohms,

A. 30
B. 40
C. 50
D. 70

16. If the charge on a single electron is 1.60×10^{-19} coulombs, then an electron volt is 1.60×10^{-19} 16.___

A. joule
B. /300 joule
C. x 300 joule
D. erg

17. Three resistors each of 12 ohms, connected in parallel with each other, are connected in series to a resistor of 6 ohms, and to a 60 volt source. 17.____
The current, in amperes, through the 6 ohms resistor will be

A. 5 B. 6 C. 10 D. 15

18. Two electrical condensers having capacitances of 9 and 18 microfarads, respectively, are connected in series. 18.____
The capacitance, in microfarads, of the two connected together will be

A. 6 B. 9 C. 13.5 D. 27

19. The current in a coil having an inductance of 32 millihenries increases in magnitude from *2 to 6* amperes in 0.05 second. 19.____
The voltage of self-induction will equal

A. 1.28 B. 1.60 C. 1.92 D. 2.56

20. A variable electrical condenser of the type used in radio sets is completely immersed in oil whose dielectric strength is 3.5. 20.____
As compared to its former state, its

A. ability to withstand high voltages has been reduced
B. capacitance has been increased
C. capacitance has been decreased
D. capacitance remains unaffected

21. The number of calories a 20-ohm electric heater operating under a potential difference of 120 volts develops in one second is APPROXIMATELY 21.____

A. 120 B. 175 C. 240 D. 720

22. An alternating current whose effective value is 100 amperes will have a peak value, in amperes, of 22.____

A. 110 B. 125 C. 136 D. 141

23. An alternating voltage is supplied to a circuit containing a capacitance C, an inductance L, and a resistance R in series with each other. 23.____
The resonant frequency is increased by

A. increasing L B. increasing C
C. decreasing R D. decreasing C

24. When resonance occurs in a circuit supplied with an alternating voltage, the 24.____

A. capacitance equals the inductance
B. inductance equals the reciprocal of the capacitance
C. inductive reactance equals the capacitative reactance
D. impedance equals zero

25. A coil with a potential difference of 20 volts across its ends develops heat at the rate of 800 calories per second. The resistance of the coil, in ohms, is 25.____

A. 0.12 B. 1.20 C. 4.00 D. 40.0

26. In a selenium rectifier, current flow practically ceases when the 26.___

A. selenium becomes negative
B. selenium becomes positive
C. accompanying alloy becomes negative
D. applied voltage exceeds the critical value

27. An alternating current generator having 4 poles rotates at 60 revolutions per second. The frequency of the current produced, in cycles per second, is 27.___

A. 60 B. 15 C. 120 D. 240

28. If an AC circuit contains resistance only, then current 28.___

A. and voltage are in phase
B. lags by 45^{o}
C. leads by 90^{o}
D. lags by 45^{o} and voltage leads by 45^{o}

29. A galvanometer has a resistance of 50 ohms and requires 0.05 amperes for full-scale deflection. 29.___
The voltage required for half-scale deflection is

A. 0.001 B. 0.05 C. 1.25 D. 2.5

30. If the capacitance in an oscillator circuit of frequency F is increased fourfold, the frequency of the oscillator becomes 30.___

A. F/4 B. F/2 C. 2F D. 4F

31. In circuit A, one ampere of AC flows for 1 hour and generates X calories. In circuit B, one ampere of DC flows for 1 hour. 31.___
The heat generated in circuit B is

A. 0.707X
B. the same as in A
C. $\frac{X}{0.707}$
D. 0.24IRT

32. A 2 and a 4 ohm resistor are connected in series and the combination is connected in parallel to a 6 ohm resistor. The TOTAL resistance, in ohms, is 32.___

A. 1.2 B. 3 C. 9 D. 12

33. The Compton effect is MOST important for its contribution to our knowledge regarding the nature of 33.___

A. radiation
B. neutrons
C. protons
D. crystal lattice structure

34. The GREATEST number of 100-watt, 110-volt electric lights that can be used simultaneously on a household line (110 volts) without burning out the 15-ampere fuse is 34.___

A. 6 B. 10 C. 16 D. 30

35. The current in the armature of a generator equipped with a commutator is 35.____

A. alternating
B. intermittent direct
C. pulsating direct
D. uniform direct

36. Eddy currents in the core of a transformer may be MINIMIZED by constructing the core of 36.____

A. laminated iron sheets in electrical contact with each other
B. laminated iron sheets insulated from each other
C. solid soft steel
D. solid hard steel

37. When 60 cycle alternating voltage is applied to a diode, the current flowing through is _______ current. 37.____

A. 30 cycle alternating
B. 60 cycle alternating
C. steady direct
D. pulsating direct

38. The earth inductor compass uses a circular coil rotating in the earth's magnetic field. MAXIMUM induced EMF will be induced when the axis of rotation is always 38.____

A. horizontal
B. vertical
C. perpendicular to the magnetic field
D. parallel to the magnetic field

39. An electric broiler has two resistors, equal in resistance, that may be connected in series or parallel by a switch. 39.____
Assuming that the line voltage is constant, the heat produced by the series connection as compared to the parallel connection will be in the ratio of

A. 1:4
B. 4:1
C. 1:2
D. 2:1

40. Three resistors of 5, 10, and 15 ohms are joined in parallel to a 120V circuit. 40.____
The equivalent resistance of this circuit, in ohms, is

A. less than 5
B. between 5 and 10
C. between 10 and 15
D. more than 15

41. A 22-volt battery has an internal resistance of 1.5 ohms. When used to supply a lamp drawing a current of 2 amperes, a voltmeter across the battery will read 41.____

A. 3
B. 19
C. 22
D. 25

42. An electron current flowing from north to south in a wire will deflect the north pole of a compass held above it 42.____

A. toward the east
B. toward the west
C. upward
D. downward

43. A capacitor, a resistor, and an inductance are connected in series. The frequency of an applied alternating voltage is varied until the circuit is in resonance with it. 43.____
The current in the circuit will

A. be minimum in value
B. be in phase with the impressed voltage

C. lead the voltage by 90°
D. lag the voltage by 90°

44. The constant current in a simple series circuit is 5 amperes and the resistance of the circuit is 10 ohms. The circuit is closed for exactly 4 minutes. 44.___
During this time, the net quantity of electricity transferred past any cross-section of the circuit is, in coulombs,

A. 20 B. 120 C. 200 D. 1200

45. If a step-down transformer is 100% efficient, the primary and secondary coils will have the same number of 45.___

A. amperes B. volts C. watts D. turns

46. When a person speaks into a telephone transmitter, the current in the primary circuit is 46.___

A. alternating
B. pulsating direct
C. reduced to zero
D. steady direct

47. To convert alternating current to direct current, one may use a(n) 47.___

A. commutator
B. transformer
C. electrostatic machine
D. induction coil

48. Kilowatt-hours may be converted into 48.___

A. ft-lb
B. ft-lb/sec
C. lb/sq. in.
D. lb/cu. ft.

49. The combined resistance of two 12-ohm resistors connected in series is _______ ohms. 49.___

A. 6 B. 12 C. 24 D. 144

50. The core of an electromagnet should be made of 50.___

A. silver
B. soft iron
C. steel
D. tungsten

KEY (CORRECT ANSWERS)

1.	C	11.	B	21.	B	31.	B	41.	B
2.	B	12.	A	22.	D	32.	B	42.	A
3.	A	13.	A	23.	D	33.	A	43.	B
4.	C	14.	A	24.	C	34.	C	44.	D
5.	C	15.	C	25.	A	35.	A	45.	C
6.	B	16.	D	26.	A	36.	B	46.	B
7.	B	17.	B	27.	C	37.	D	47.	A
8.	D	18.	A	28.	A	38.	C	48.	A
9.	D	19.	D	29.	C	39.	A	49.	C
10.	A	20.	B	30.	B	40.	A	50.	B

TEST 2

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. The potential expressed in e.s.u. at a point midway between two equal positive charges of 50 statcoulombs (e.s.u.) placed 10 cm apart is 1.___

   A. +4 B. +5 C. +10 D. +20

2. Eddy currents in the core of a transformer may be minimized by constructing the core of 2.___

   A. laminated iron sheets in electrical contact with each other
   B. laminated iron sheets insulated from each other
   C. solid soft steel
   D. solid hard steel

3. When 60 cycle alternating voltage is applied to a diode, the current flowing through is _______ current. 3.___

   A. 30 cycle alternating B. 60 cycle alternating
   C. steady direct D. pulsating direct

4. The earth inductor compass uses a circular coil rotating in the earth's magnetic field. Maximum induced EMF will be induced when the axis of rotation is always 4.___

   A. horizontal
   B. vertical
   C. perpendicular to the magnetic field
   D. parallel to the magnetic field

5. An electric broiler has two resistors, equal in resistance, that may be connected in series or parallel by a switch. 5.___
   Assuming that the line voltage is constant, the heat produced by the series connection as compared to the parallel connection will be in the ratio of

   A. 1:4 B. 4:1 C. 1:2 D. 2:1

6. Three resistors of 5, 10, and 15 ohms are joined in parallel to a 120V circuit. The equivalent resistance of this circuit, in ohms, is 6.___

   A. less than 5 B. between 5 and 10
   C. between 10 and 15 D. more than 15

7. A 22-volt battery has an internal resistance of 1.5 ohms. When used to supply a lamp drawing a current of 2 amperes, a voltmeter across the battery will read 7.___

   A. 3 B. 19 C. 22 D. 25

8. An electron current flowing from north to south in a wire will deflect the north pole of a compass held above it 8.___

   A. toward the east B. toward the west
   C. upward D. downward

9. A capacitor, a resistor, and an inductance are connected in series. The frequency of an applied alternating voltage is varied until the circuit is in resonance with it. The current in the circuit will 9.____

A. be minimum in value
B. be in phase with the impressed voltage
C. lead the voltage by 90°
D. lag the voltage by 90°

10. A 2 and a 4 ohm resistor are connected in series and the combination is connected in parallel to a 6 ohm resistor. The TOTAL resistance, in ohms, is 10.____

A. 1.2 B. 3 C. 9 D. 12

11. The Compton effect is MOST important for its contribution to our knowledge regarding the nature of 11.____

A. radiation
B. neutrons
C. protons
D. crystal lattice structure

12. Assume that the movable coil of a D'Arsonval type of voltmeter has a resistance of 300 ohms and a current of 0.02 ampere will give a full-scale reading. The series resistance, in ohms, needed to construct a voltmeter with a full scale of 150 volts is 12.____

A. 7200 B. 8100 C. 7800 D. 7500

13. An alternating voltage is supplied to a circuit consisting of an incandescent lamp and a coil of many turns. The current in the circuit 13.____

A. lags behind the voltage
B. leads the voltage
C. is in phase with the voltage
D. is rectified into direct current

14. The number of calories a 20-ohm electric heater operating under a potential difference of 120 volts develops in one second is APPROXIMATELY 14.____

A. 120 B. 175 C. 240 D. 720

15. An alternating current whose effective value of 100 amperes will have a peak value, in amperes, of 15.____

A. 110 B. 125 C. 136 D. 141

16. By inductively feeding back energy from the plate circuit into the grid circuit, a triode may be used as a(n) 16.____

A. demodulator
B. amplifier
C. detector
D. diode

17. When a current of 2 amperes flows through a conductor of 2 ohms resistance for 3 seconds, the heat produced, in joules, is 17.____

A. 12 B. 24 C. 36 D. 72

18. A length of wire, diameter 2 mils, has a resistance of 6 ohms. 18.____
The same length of wire of the same material having a diameter of 4 mils has a resistance, in ohms, of

A. 1.5 B. 3 C. 12 D. 24

19. The generalization that the algebraic sum of the currents at a junction in a circuit equals zero was postulated by 19.____

A. Ohm B. Kirchhoff C. Onnes D. Seebeck

20. It is desired to charge an electroscope negatively by induction. 20.____
One of the steps that must be performed is to

A. use a negatively charged rod
B. remove positive charges
C. remove electrons
D. ground the electroscope

21. A series AC circuit contains an inductance L, a capacitance C, and a resistor R. 21.____
The impedance of this circuit equals

A. $R^2 + X_L + X_C$
B. $\sqrt{R^2 + (X_L - X_C)^2}$
C. $R^2 + \sqrt{X_L - X_C}$
D. $R^2 - X_L - X_C^2$

22. In an AC circuit in which the current and voltage are out of phase by 90°, an ammeter reads 2 and a voltmeter reads 120. 22.____
The power expended by this circuit, in watts, equals

A. zero B. 60 C. 120 D. 240

23. A voltmeter showed a reading, when connected to a circuit carrying a sinusoidal alternating current, of 100 volts (RMS value). 23.____
The MAXIMUM instantaneous voltage was

A. 100 B. 141 C. 173 D. 200

24. A condenser of capacitance C is charged to a potential V by a quantity of charge Q. 24.____
The energy stored in the condenser is

A. 1/2CV B. $1/2CV^2$ C. CV D. $1/2CQ^2$

25. Two 50-watt, 120-volt heaters are connected in parallel to a 120-volt DC line. The power consumption is now X times as great as it would be if they were connected in series. Assuming no change in resistance, X will be 25.____

A. 2 B. 1/2 C. 1/4 D. 4

26. The wire in the primary of a step-up transformer is USUALLY of larger diameter than the wire in the secondary because the primary has the higher 26.____

A. voltage
B. resistance
C. current
D. number of turns

27. A spark coil operated in the classroom can produce a spark about 2 inches long. This represents a voltage of about 27.____

A. 400 B. 4000 C. 40,000 D. 400,000

28. A substance with a magnetic permeability less than one is called 28.____

A. ferromagnetic
B. diamagnetic
C. paramagnetic
D. isomagnetic

29. The constant current in a simple series circuit is 5 amperes and the resistance of the circuit is 10 ohms. The circuit is closed for exactly 4 minutes. 29.____
During this time, the net quantity of electricity transferred past any cross-section of the circuit is, in coulombs,

A. 20 B. 120 C. 200 D. 1200

30. The Curie point is the 30.____

A. temperature at which a magnetic substance loses its magnetism
B. temperature above which a gas cannot be liquefied by pressure
C. pressure needed to inhibit radioactivity
D. temperature at which the addition of heat causes contraction

31. A 0-10 milliampere meter has a resistance of 20 ohms. To convert this meter to an ammeter with a range of 0-1 ampere, one should connect a resistance of APPROXIMATELY 31.____

A. 1/5 ohm in parallel
B. 200 ohms in series
C. 2000 ohms in parallel
D. 2000 ohms in series

32. An alternating voltage is supplied to a circuit containing a capacitance C, an inductance L, and a resistance R in series with each other. 32.____
The resonant frequency is increased by

A. increasing L
B. increasing C
C. decreasing R
D. decreasing C

33. When resonance occurs in a circuit supplied with an alternating voltage, the 33.____

A. capacitance equals the inductance
B. inductance equals the reciprocal of the capacitance
C. inductive reactance equals the capacitative reactance
D. impedance equals zero

34. The phase angle in an alternating current circuit is zero degrees when the circuit 34.____

A. contains resistance *only*
B. contains inductance *only*
C. contains capacitance *only*
D. is not closed

35. When a capacitor of 10 microfarads capacity is connected to a 100 volt current source, the charge acquired by the capacitor will have a magnitude, in coulombs, of 35.____

A. 10^{-6} B. 10^{-4} C. 10^{2} D. 10^{3}

36. The efficiency in percent of a one horsepower motor drawing 8.0 amperes at 125 volts is APPROXIMATELY 36.___

A. 60 B. 75 C. 85 D. 90

37. The product of the pole strength of a bar magnet and the distance between the poles is called the magnetic 37.___

A. moment
B. flux
C. field intensity
D. reluctance

38. Assume that a length of wire having a resistance of 20 ohms is cut into four equal lengths. The four resistors then are connected in parallel with each other and their resistance measured. 38.___
The resistance, in ohms, will be

A. 1.25 B. 2.50 C. 5 D. 10

39. Two adjacent turns in a helical coil through which a constant current is passing will 39.___

A. repel each other
B. attract each other
C. have no effect on each other
D. have a voltage induced in them

40. When several capacitors are connected in series and to a source of direct current, each capacitor must have the SAME 40.___

A. voltage
B. dielectric strength
C. charge
D. capacitance

41. The current in an alternating current circuit is equal to the voltage multiplied by 41.___

A. the impedance
B. admittance
C. capacitance
D. inductance

42. Three identical resistors connected in parallel have a total resistance of 10 ohms. 42.___
If these resistors are separated and then connected to each other in series, the TOTAL resistance, in ohms, will be

A. 3.3 B. 10.0 C. 30.0 D. 90.0

43. A transformer has 100 turns in its primary winding and 1000 turns in its secondary winding. 43.___
If a 1.5 volt dry cell is connected across the primary winding, the steady state voltage across the secondary winding will be

A. 15 volts AC
B. 15 volts DC
C. 0.15 volts DC
D. zero

44. A long wire at a constant height above the ground is carrying electron current from the east to the west. 44.___
The direction of the magnetic field, due to the current, at a point on the ground directly under the wire is

A. north B. south C. up D. down

45. A 9-volt battery is connected to an 18 ohm resistor. 45.____
If the internal resistance of the battery is 9 ohms, the current in the circuit, in amperes, is

A. 1/3 B. 1/2 C. 3 D. 36

46. An electric circuit carries a current of 2.0 amperes. 46.____
The quantity of electric charge that passes a given point in the circuit in 6.0 seconds, in coulombs, is

A. 1.5 B. 2.0 C. 3.0 D. 12.0

47. A 10 microfarad parallel plate capacitor is modified by doubling the area of its plates and doubling the distance between the plates. 47.____
The capacitance, in microfarads, after modification is

A. 5 B. 10 C. 20 D. 40

48. A straight horizontal wire 3 meters long and carrying a current of 4 amperes is in a uniform vertical magnetic field having a strength of 5 tesla. 48.____
The force, in newtons, exerted by the magnetic field on the wire is

A. 2.4 B. 6.7 C. 12.0 D. 60.0

49. If the impedance of a 110 volt circuit is 44 ohms, the current, in amperes, flowing in the circuit will be 49.____

A. 0.25 B. 0.4 C. 2.5 D. 66.0

50. If a 120-volt AC source is connected to a 10 ohm resistance, a 10 ohm inductive reactance, and a 10 ohm capacitive reactance all in series, the resultant current, in amperes, is 50.____

A. 3.1 B. 4.0 C. 4.4 D. 12.0

KEY (CORRECT ANSWERS)

1. D	11. A	21. B	31. A	41. B
2. B	12. A	22. A	32. D	42. C
3. D	13. A	23. B	33. C	43. B
4. C	14. B	24. B	34. A	44. A
5. A	15. D	25. D	35. B	45. A
6. A	16. B	26. C	36. B	46. D
7. B	17. B	27. C	37. A	47. D
8. A	18. A	28. B	38. A	48. D
9. B	19. B	29. D	39. B	49. C
10. B	20. D	30. A	40. C	50. D

EXAMINATION SECTION
TEST 1

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. Three resistors, each of 12 ohms, connected in parallel with each other, are connected in series to a resistor of 6 ohms and to a 60 volt source. 1.____
The current, in amperes, through the 6 ohms resistor will be

A. 5 B. 6 C. 10 D. 15

2. Two electrical condensers have capacitances of 9 and 18 microfarads, respectively, are connected in series. 2.____
The capacitance, in microfarads, of the two connected together will be

A. 6 B. 9 C. 13.5 D. 27

3. The current in a coil having an inductance of 32 millihenries increases in magnitude from 2 to 6 amperes in 0.05 second. 3.____
The voltage of self-induction will equal

A. 1.28 B. 1.60 C. 1.92 D. 2.56

4. A variable electrical condenser of the type used in radio sets is completely immersed in oil whose dielectric strength is 3.5. 4.____
As compared to its former state, its

A. ability to withstand high voltages has been reduced
B. capacitance has been increased
C. capacitance has been decreased
D. capacitance remains unaffected

5. A shunt motor having an armature whose resistance is 0.5 ohm is attached to a 120 volt supply. The armature current at full speed is 10 amperes. 5.____
The back EMF, in volts, will be

A. 5 B. 10 C. 115 D. 125

6. An electron stream sent horizontally through a magnetic field whose lines of force are horizontal and at right angles to the electron stream will 6.____

A. curve in a horizontal plane
B. curve in a vertical plane
C. curve in a plane neither horizontal nor vertical
D. pass through without curving

7. In a series wound DC electrical generator, the current in the line is 7.____

A. the same as the field current
B. half the current through either brush
C. twice the current through either brush
D. independent of the field current

8. The MOST economical 0.1 mfd condenser to be used, without danger of shorting, on a 250-volt AC line is one whose DC working voltage is rated at 8.____

A. 250 B. 300 C. 400 D. 600

9. As the frequency of an alternating EMF in a given circuit increases, the current in the circuit at first increases, then decreases. 9.____
The circuit contains

A. only capacitative reactance
B. only inductive reactance
C. both capacitative and inductive reactance
D. a constant impedance

10. A storage cell is connected in series with a resistance of 0.3 ohms. 10.____
If the resistance of the cell is 0.2 ohms and its EMF is 2.5 volts, the current, expressed in amperes, in the circuit is

A. 1/5 B. 5 C. 7.5 D. 12.5

11. A battery has an open circuit voltage of 20 volts and an internal resistance of 0.25 ohm. When it delivers a current of 10 amperes, the terminal voltage will be 11.____

A. 15 B. 17.5 C. 18 D. 20

12. The core of an electromagnet is made of soft iron because soft iron 12.____

A. is an electrical conductor
B. is easily magnetized and demagnetized
C. is easy to shape
D. retains its magnetism

13. The wire in the primary of a step-up transformer is usually thicker than the wire in the secondary because the primary has the 13.____

A. higher current B. higher resistance
C. higher voltage D. lower current

14. Direct current is necessary in order to 14.____

A. charge storage batteries
B. operate lights
C. produce heat
D. run electric motors

15. Very small electric currents are measured by a(n) 15.____

A. galvanometer B. micrometer
C. ohmmeter D. wattmeter

16. Of the following, the STRONGEST electromagnet is one having ______ amperes and ______ turns. 16.____

A. 5; 10 B. 10; 5 C. 5; 5 D. 10; 10

17. In describing an alternating current, the term *60 cycles per second* refers to the 17.____

A. amplitude B. frequency C. voltage D. wavelength

18. In a parallel circuit, the device with the LOWEST resistance has the 18.____

A. least heating effect
B. highest wattage
C. lowest current
D. lowest voltage drop

19. When a current is made to flow in a circuit consisting of two unlike metals, heat is absorbed at one of the junctions and given off at the other junction. 19.____
This phenomenon is known as the _______ effect

A. Tyndall
B. Stark
C. Purkinje
D. Peltier

20. Assume that a length of wire having a resistance of 20 ohms is cut into four equal lengths. The four resistors then are connected in parallel with each other and their resistance measured. 20.____
The resistance, in ohms, will be

A. 1.25
B. 2.50
C. 5
D. 10

21. Two adjacent turns in a helical coil through which a constant current is passing will 21.____

A. repel each other
B. attract each other
C. have no effect on each other
D. have a voltage induced in them

22. When several capacitors are connected in series and to a source of direct current, each capacitor must have the same 22.____

A. voltage
B. dielectric strength
C. charge
D. capacitance

23. The current in an alternating current circuit is equal to the voltage multiplied by the 23.____

A. impedance
B. admittance
C. capacitance
D. inductance

24. The penetrating power of the x-rays produced by a Coolidge x-ray tube can be increased by increasing the 24.____

A. number of electrons emitted from the filament
B. distance between cathode and anode
C. mass of the anode
D. voltage between cathode and anode

25. The combined resistance, in ohms, of four 100-ohm resistors connected in series is 25.____

A. 100
B. 200
C. 25
D. 400

26. Four resistors of sixty ohms each are connected in parallel. 26.____
Their combined resistance, in ohms, is

A. 15
B. 30
C. 60
D. 240

27. Resistors of 5, 10, 15, and 30 ohms are connected in series to a battery. 27.____
The GREATEST voltage drop will be across the resistor of _______ ohms.

A. 5
B. 10
C. 15
D. 30

28. Eight Christmas tree lamps are connected in series on a 120-volt circuit. The voltage across each lamp is 28.___

A. 15 B. 112 C. 120 D. 960

29. A flow of electricity in a copper wire consists of a movement of 29.___

A. ions B. electrons C. positrons D. protons

30. A wire 50 feet long has a resistance of 10 ohms. The resistance of 25 feet of this wire is ______ ohms. 30.___

A. 2.5 B. 5 C. 20 D. 40

31. All of the following devices can be operated from a steady direct current EXCEPT a 31.___

A. flatiron
B. rheostat
C. toaster
D. transformer

32. The alloy used for lead-in wires of electric lamps is chosen PRINCIPALLY because it 32.___

A. does not expand on heating
B. expands at the same rate as glass
C. has a high specific heat
D. has a low melting point

33. A voltmeter is a galvanometer that has its movable coil connected with a ______ resistance in ______. 33.___

A. high; parallel
B. high; series
C. low; parallel
D. low; series

34. A commutator on a direct-current motor 34.___

A. reverses the direction of the current in the field magnet
B. reverses the direction of the current in the armature coils
C. changes low voltage DC to higher voltage DC
D. changes low voltage AC to higher voltage AC

35. One great advantage of AC over DC is that AC 35.___

A. can be stored
B. can be transmitted more economically
C. operates heating devices better
D. requires less insulation

36. Steady direct current cannot be used to operate a(n) 36.___

A. doorbell
B. electric heater
C. lamp
D. transformer

37. Only direct-current electricity may be used to 37.___

A. operate a transformer
B. charge a storage battery
C. heat a radio-tube filament
D. operate a doorbell

38. In speaking of 60-cycle alternating current, the term *60 cycle* refers to 38.____

A. amplitude
B. frequency
C. velocity
D. wavelength

39. Of the following, the device that should NOT be connected to a DC source is a 39.____

A. flatiron
B. heating coil
C. lamp
D. transformer

40. The armature in an electric doorbell moves away from the magnet because it is 40.____

A. moved back by the electromagnet
B. moved back by the spring
C. repelled by the gong
D. repelled by the interrupter

41. A condenser is used to 41.____

A. change AC to DC
B. charge batteries
C. generate electricity
D. store electricity

42. The potential difference in a circuit is measured in 42.____

A. amperes B. ohms C. volts D. watts

43. The current in a fuse is ______ the current in the circuit it protects. 43.____

A. much less than
B. the same as
C. slightly greater than
D. much greater than

44. A condenser is connected in series with a 25-watt lamp to a 120-volt DC source. The lamp will 44.____

A. operate normally
B. burn out
C. glow dimly
D. not operate

45. A galvanometer has a resistance of 50 ohms and requires 0.05 amperes for full-scale The voltage required for half-scale deflection is 45.____

A. 0.0001 B. 0.05 C. 1.25 D. 2.5

46. If the capacitance in an oscillator circuit of frequency F is increased fourfold, the frequency of the oscillator becomes 46.____

A. F/4 B. F/2 C. 2F D. 4F

47. In circuit A, one ampere of AC flows for 1 hour and generates X calories. In circuit B, one ampere of DC flows for 1 hour.
The heat generated in circuit B is 47.____

A. 0.707X
B. the same as in A
C. $\frac{X}{0.707}$
D. 0.24 IRT

48. Two 50-watt, 120-volt heaters are connected in parallel to a 120-volt DC line. The power consumption is now X times as great as it would be if they were connected in series. Assuming no change in resistance, X will be 48.___

A. 2 B. 1/2 C. 1/4 D. 4

49. In an AC circuit in which the current and voltage are out of phase by 90°, an ammeter reads 2 and a voltmeter reads 120. 49.___
The power expended by this circuit, in watts, equals

A. zero B. 60 C. 120 D. 240

50. A voltmeter showed a reading, when connected to a circuit carrying a sinusoidal alternating current, of 100 volts (RMS value). 50.___
The MAXIMUM instantaneous voltage was

A. 100 B. 141 C. 173 D. 200

KEY (CORRECT ANSWERS)

1. B	11. B	21. B	31. D	41. D
2. A	12. B	22. C	32. B	42. C
3. D	13. A	23. B	33. B	43. B
4. B	14. A	24. D	34. B	44. D
5. C	15. A	25. D	35. B	45. C
6. B	16. D	26. A	36. D	46. B
7. A	17. B	27. D	37. B	47. B
8. C	18. B	28. A	38. B	48. D
9. C	19. D	29. B	39. D	49. A
10. B	20. A	30. B	40. B	50. B

TEST 2

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. A three-element vacuum tube in an electric circuit 1.______

   A. generates signals of increased voltage
   B. amplifies the grid bias
   C. controls the electron flow in the circuit
   D. rectifies the B-battery output
   E. increases the signal frequency

2. A simple series circuit consists of a cell, an ammeter, and a rheostat of resistance R. The ammeter reads 5 amps. When the resistance of the rheostat is increased by 2 ohms, the ammeter reading drops to 4 amps. 2.______
   The original resistance, in ohms, of the rheostat R is

   A. 2.5 B. 4.0 C. 8.0 D. 10.0 E. 12.0

3. Two lamps need 50V and 2 amp each in order to operate at a desired brilliancy. 3.______
   If they are to be connected in series across a 120V line, the resistance, in ohms, of the rheostat that must be placed in series with the lamps needs to be

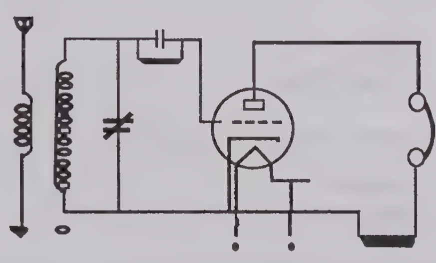
   A. 4 B. 10 C. 20 D. 100 E. 200

4. As the photon is a quantum in electromagnetic field theory, which one of the following is considered to be the quantum in the nuclear field? 4.______

   A. Neutrino B. Electron C. Meson
   D. Neutron E. None of the above

5. Which symbol represents an electrical ground connection? 5.______

6. Which of the following circuits could you wire from the diagram at the right? 6.______
   A. Code oscillator
   B. Doorbell system
   C. Electric chime
   D. Radio receiving set
   E. Electric train signal



7. The rate of electron flow in an electric circuit is measured with a(n) 7.______

   A. ammeter B. voltmeter C. ohmmeter
   D. wattmeter E. none of the above

8. Which one of the following is characteristic of a parallel electrical circuit? 8.____

   A. The current is the same in all parts of the circuit.
   B. The voltage across all the branches is the same.
   C. A break through any part of the circuit will stop the flow of current throughout the circuit.
   D. The total resistance is equal to the sum of the resistances of the component parts.

9. When sphere A, with a large negative charge, is touched by sphere B, with a smaller negative charge, which one of the following will occur? 9.____

   A. Electrons flow from A to B
   B. Electrons flow from B to A
   C. Protons flow from A to B
   D. Protons flow from B to A

10. Rectifiers are LEAST often made from which one of the following elements? 10.____

    A. Si B. Ge C. Se D. Cu

11. Which of the following is GENERALLY used to convert a galvanometer to an ammeter? 11.____

    A. Capacitor B. Inductor
    C. Oscillator D. Resistor

12. The tuned circuits of a radio receiver consist BASICALLY of which one of the pairs of components below? 12.____

    A. Rectifier and antenna
    B. Tube or transistor and coil
    C. Potentiometer and oscillator
    D. Capacitor and coil

13. Often a 2-ohm and a 4-ohm resistor are connected to a 12-volt battery in series. The number of amperes flowing through the 2-ohm resistor is 13.____

    A. 0.5 B. 1 C. 2 D. 6

14. A radio wave 6 meters long will have a frequency CLOSEST to which one of the following? 14.____

    A. 6 cycles B. 6 kilocycles
    C. 6 megacycles D. 50 megacycles

15. Which one of the instruments below sometimes uses an internal battery? 15.____

    A. Ammeter B. Voltmeter
    C. Wattmeter D. Ohmmeter

16. Which one of the following kinds of rays is bent MOST by a magnetic field? 16.____

    A. Alpha B. Beta C. Gamma D. Cosmic

17. A battery having an emf of 6.0 volts and an internal resistance of 0.20 ohms is being The charging current is 10 amperes. 17.____
    The potential difference at the terminals of the battery is, in volts, which one of the following?

A. 4.0 B. 5.8 C. 6.0 D. 8.0

18. Whenever magnetic lines of force are cut by a conductor, 18.____

A. an induced current results
B. a magnetic field is induced
C. an emf is induced
D. the motion will be opposed by an induced magnetic field

19. The oil drop experiment performed by Robert Millikan was used to measure 19.____

A. energy of emitted photoelectrons
B. charge of an electron
C. thin film interference
D. surface tension of oil

20. Of the following, a dielectric is MOST similar to a(n) 20.____

A. conductor B. capacitor
C. inductor D. insulator

21. To measure the electric power consumed by a direct current circuit, the MINIMUM apparatus required is a(n) 21.____

A. ammeter B. voltmeter
C. ammeter and a voltmeter D. ohmmeter

22. An AC circuit has a capacitive reactance of 100 ohms, an inductive reactance of 100 ohms, and a resistance of 100 ohms.
The impedance, in ohms, of the circuit is 22.____

A. 33.3 B. 100 C. 150 D. 300

23. A series electric circuit consists of a 20 ohm resistor, a 10 volt battery, and a switch.
If the switch is closed for 6 seconds, the energy consumed by the circuit, in joules, is 23.____

A. 10 B. 20 C. 30 D. 40

24. A 10 ohm resistor and a 50 ohm resistor are connected in parallel.
If the current in the 10 ohm resistor is 5 amperes, the current, in amperes, in the 50 ohm resistor will be 24.____

A. 1 B. 5 C. 25 D. 50

25. Assuming a core of adequate size, of the following, the MOST powerful electromagnet would have _______ turns and draw _______ amperes. 25.____

A. 100; 6 B. 50; 13 C. 200; 2 D. 150; 5

26. Resistors of 2 ohms, 4 ohms, and 6 ohms are connected in series to a 24 volt battery.
The current, in amps, through the 4 ohm resistor is 26.____

A. 2 B. 4 C. 6 D. 22

27. An electric circuit consisting of a 10V battery and two resistors connected in series has 5 amperes of current. If a 5 microfarad capacitor is placed in series with the resistors, the current after a few minutes will be 27.____

A. 5 amperes
B. more than 5 amperes
C. between 1 and 5 amperes
D. zero

28. Resistance CANNOT be measured if the only instruments available are a voltmeter and a(n) 28.____

A. ammeter
B. Wheatstone Bridge
C. galvanometer
D. ohmmeter

29. In the absence of external magnetic fields, ground state electronic energy levels depend ALMOST ENTIRELY on the quantum numbers 29.____

A. n and m_1 B. n and 1 C. m_1 and m_s D. 1 and m_s

30. A small object having a charge of -2 microcoulombs is placed in a uniform electric field of 10 volts/meter. 30.____
The force, in micronewtons, on the object due to the electric field is

A. 0.2 B. 5.0 C. 8.0 D. 20.0

31. A 50 microfarad capacitor is fully charged by a 100 volt power supply. 31.____
The electric energy, in joules, stored in the capacitor is

A. 0.25 B. 0.50 C. 1.50 D. 5.00

32. A thin-walled, hollow metal sphere has a diameter of 2.0 meters and is given a charge of +9 microcoulombs. 32.____
The electric potential 8.0 meters above the top of the sphere, in volts, is

A. 80 B. 1000 C. 1200 D. 9000

33. Assume that a length of wire having a resistance of 20 ohms is cut into four equal lengths. The four resistors then are connected in parallel with each other and their resistance measured. 33.____
The resistance, in ohms, will be

A. 1.25 B. 2.50 C. 5 D. 10

34. Two adjacent turns in a helical coil through which a constant current is passing will 34.____

A. repel each other
B. attract each other
C. have no effect on each other
D. have a voltage induced in them

35. When several capacitors are connected in series and to a source of direct current, each capacitor must have the same 35.____

A. voltage
B. dielectric strength
C. charge
D. capacitance

36. The current in an alternating current circuit is equal to the voltage multiplied by the 36.____

A. impedance
B. admittance
C. capacitance
D. inductance

37. The penetrating power of the x-rays produced by a Coolidge x-ray tube can be increased by increasing the 37._____

A. number of electrons emitted from the filament
B. distance between cathode and anode
C. mass of the anode
D. voltage between cathode and anode

38. A shunt motor having an armature whose resistance is 0.5 ohm is attached to a 120 volt supply. The armature current at full speed is 10 amperes. 38._____
The back EMF, in volts, will be

A. 5 B. 10 C. 115 D. 125

39. An electron stream sent horizontally through a magnetic field whose lines of force are horizontal and at right angles to the electron stream will 39._____

A. curve in a horizontal plane
B. curve in a vertical plane
C. curve in a plane neither horizontal nor vertical
D. pass through without curving

40. In a series wound DC electrical generator, the current in the line is 40._____

A. the same as the field current
B. half the current through either brush
C. twice the current through either brush
D. independent of the field current

41. The MOST economical 0,1 mfd condenser to be used, without danger of shorting, on a 250 volt AC line is one whose DC working voltage is rated at 41._____

A. 250 B. 300 C. 400 D. 600

42. As the frequency of an alternating EMF in a given circuit increases, the current in the circuit at first increases, then decreases. 42._____
The circuit contains

A. only capacitative reactance
B. only inductive reactance
C. both capacitative and inductive reactance
D. a constant impedance

43. A storage cell is connected in series with a resistance of 0.3 ohms. 43._____
If the resistance of the cell is 0.2 ohms and its EMF is 2.5 volts, the current, expressed in amperes, in the circuit is

A. 1/5 B. 5 C. 7.5 D. 12.5

44. A condenser of capacitance C is charged to a potential V by a quantity of charge Q. 44._____
The energy stored in the condenser is

A. 1/2CV B. $1/2CV^2$ C. CV D. $1/2CQ^2$

45. Two 50-watt, 120-volt heaters are connected in parallel to a 120-volt DC line. The power consumption is now X times as great as it would be if they were connected in series. Assuming no change in resistance, X will be 45.____

A. 2 B. 1/2 C. 1/4 D. 4

46. The wire in the primary of a step-up transformer is usually of larger diameter than the wire in the secondary because the primary has the higher 46.____

A. voltage
B. resistance
C. current
D. number of turns

47. A spark coil operated in the classroom can produce a spark about 2 inches long. This represents a voltage of about 47.____

A. 400 B. 4000 C. 40,000 D. 400,000

48. A substance with a magnetic permeability less than one is called 48.____

A. ferromagnetic
B. diamagnetic
C. paramagnetic
D. isomagnetic

49. The constant current in a simple series circuit is 5 amperes and the resistance of the circuit is 10 ohms. The circuit is closed for exactly 4 minutes. During this time, the net quantity of electricity transferred past any cross-section of the circuit is, in coulombs, 49.____

A. 20 B. 120 C. 200 D. 1200

50. The Curie point is the 50.____

A. temperature at which a magnetic substance loses its magnetism
B. temperature above which a gas cannot be liquefied by pressure
C. pressure needed to inhibit radioactivity
D. temperature at which the addition of heat causes contraction

KEY (CORRECT ANSWERS)

1.	C	11.	D	21.	C	31.	B	41.	C
2.	C	12.	D	22.	B	32.	C	42.	C
3.	B	13.	C	23.	C	33.	A	43.	B
4.	C	14.	D	24.	A	34.	B	44.	B
5.	C	15.	D	25.	D	35.	C	45.	D
6.	D	16.	B	26.	A	36.	B	46.	C
7.	A	17.	D	27.	D	37.	D	47.	C
8.	B	18.	C	28.	C	38.	C	48.	B
9.	A	19.	B	29.	A	39.	B	49.	D
10.	D	20.	D	30.	D	40.	A	50.	A

EXAMINATION SECTION
TEST 1

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. The majority of simple electronics circuits are based upon a logic 1

   A. A and a logic B state
   B. *on* and a logic *off* state
   C. 0 and a logic 1 state
   D. *go* and *no-go* state

2. What voltage level exists in the 7400-series of 1C chips? 2

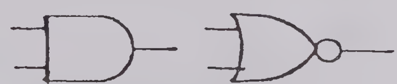
   A. -15 volts, ground, and +5 volts
   B. Ground, +5 volts, and +12 volts
   C. -12 volts, ground, and +5 volts
   D. +5 volts and ground

3. A clock pulse is a transition 3

   A. from a logic 0 to a logic 1
   B. from a logic 1 to a logic 0
   C. from a logic 0 to a logic 1 and back to logic 0
   D. both A and B are correct

4. The symbols shown to the right are those for a 2-input ______ gate and 2-input ______ gate. 4

   A. AND; NOR
   B. EXCLUSIVE-OR; NAND
   C. OR; NOR
   D. AND; NAND



5. For which type of gate is the following definition CORRECT? 5
   A binary circuit with two or more inputs and single output, in which the output is a logic 1 only when all inputs are logic 1, and the output is logic 0 if any one of the inputs is logic 0.

   A. AND gate B. NAND gate C. OR gate D. NOR gate

6. If the two inputs to a 2-input AND, NAND, OR, and NOR gate are both at logic 1, the outputs from the four gates are 6

   A. 1,1,0 and 0
   B. 1,0,0 and 1
   C. 0,1,1 and 0
   D. 1,0,1 and 0

7. The term *to enable* a gate is the opposite of which of the following terms?

   A. To close a gate
   B. To disable a gate
   C. To block a gate
   D. All of the above

8. A gate and a switch differ in which of the following ways?

   A. A gate is essentially a one-way device, whereas a switch is a two-way device.
   B. When a gate is closed, a signal can pass; when a switch is closed, a signal cannot pass,
   C. When a gate is open, a signal can pass; when a switch is closed, a signal cannot pass.
   D. A gate and a switch are identical in function.

9. A gating input of logic 0 to a 2-input NOR gate will allow what type of digital information to appear at the output of the gate?

   A. Logic 1 state
   B. Logic 0 state
   C. Unchanged input data
   D. Inverted input data

10. A gating input of logic 0 to a 2-input NAND gate will allow what type of digital information to appear at the output of the gate?

    A. Logic 1 state
    B. Logic 0 state
    C. Unchanged input data
    D. Inverted input data

11. The 7400, 7402, 7408, and 7432 IC chips each contain

    A. *only* a single gate
    B. four gates
    C. three gates
    D. two gates

12. A common-anode 7 segment display has the following inputs to its segments: A, D, E=1 and B, C, F, G = 0.
    What does the display read out?

    A. Nine
    B. Four
    C. Six
    D. Three
    E. None of these

13. A common cathode display has the following inputs to its segments: C,F.=0 and A,B,D,E,G=1.
    What does the display indicate?

    A. Nine
    B. Four
    C. Two
    D. Five

14. What is the difference between a 7490 and a 7493 counter?

    A. There is no difference.
    B. The 7490 is a decade counter, whereas the 7493 is a binary counter.
    C. The 7490 is a binary counter, whereas the 7493 is a decade counter.
    D. They have different pin configurations

15. The truth table to the right applies for the ______ gate.

    A. AND
    B. OR
    C. NAND
    D. NOR
    E. None of these

IN	OUT
AB	X
00	1
01	1
10	1
11	1

16. In the truth tables for a 2-input AND, NAND, OR, and NOR gate, the unique output state is, respectively, 16.___

A. logic 1, logic 1, logic 0, logic 1
B. logic 1, logic 0, logic 0, logic 1
C. logic 0, logic 1, logic 1, logic 1
D. logic 1, logic 1, logic 1, logic 1

17. When one inverts the output from an AND gate, he converts it into a(n) _______ gate. 17.___

A. EXCLUSIVE-OR
B. NAND
C. NOR
D. AND-OR-INVERT

18. If the two inputs to a 2-input AND gate and a 2-input NOR gate are left unconnected, the outputs from these two gates are, respectively, 18.___

A. logic 1 and logic 0
B. logic 0 and logic 1
C. logic 0 and logic 0
D. logic 1 and logic 1

19. The 7400, 7420, and 7430 IC chips have gates that have, respectively, the following numbers of inputs: 19.___

A. two, three, five, and ten
B. one, two, three, four
C. two, three, four, eight
D. two, three, four, six

20. The 7400, 7420, 7430 IC chips are all _______ gates. 20.___

A. AND
B. NAND
C. both AND and NAND
D. NOR

21. A four decade counter can count from 21.___

A. 0001 to 10000
B. 0001 to 9999
C. 0000 to 9999
D. 0000 to 100000

22. In a positive clock pulse, the transition from logic 1 to logic 0 occurs on the _______ edge. 22.___

A. positive trailing
B. positi.ve leading
C. negative trailing
D. negative leading

23. The 74121-IC chip is a 23.___

A. counter
B. flip-flop
C. monostable multivibrator
D. programmable timer

24. When one debounces a SPDT switch, he 24.___

A. makes sure that the switching action occurs quickly
B. makes sure that the output from the switch can be controlled to produce a single clock pulse at a time
C. turns the SPDT into, basically, a monostable multivibrator
D. none of the above

25. When R=l megohm and C=l microfarad, the RC time constant has a value of 25.___

A. 1 second
B. .000001 seconds
C. .001 seconds
D. .000001 hz

KEY (CORRECT ANSWERS)

1.	C	11.	B
2.	D	12.	E
3.	C	13.	C
4.	A	14.	B
5.	A	15.	E
6.	D	16.	B
7.	D	17.	B
8.	A	18.	A
9.	D	19.	C
10.	A	20.	B

21.	C
22.	C
23.	C
24.	B
25.	A

TEST 2

DIRECTIONS: Each question or incomplete statement is followed by several suggested answers or completions. Select the one that BEST answers the question or completes the statement. *PRINT THE LETTER OF THE CORRECT ANSWER IN THE SPACE AT THE RIGHT.*

1. In HEXADECIMAL notation, the binary number DCBA = 1100 represents either ______ or the letter ______.

   A. eleven; B
   B. eleven; A
   C. twelve; C
   D. thirteen; D

2. The binary number, 11111, represents which of the following decimal numbers?

   A. 32
   B. 16
   C. 15
   D. 3

3. A twelve-bit binary number can encode ______ decimal numbers.

   A. two thousand and forty-eight
   B. four thousand and ninety-six
   C. five hundred and twelve
   D. two hundred and fifty-six

4. The binary number, 1111, appears on the seven-segment LED display as a

   A. blank display
   B. decimal 15
   C. the letter F
   D. 0

5. The LARGEST binary number that can exist in binary-coded decimal (BCD) is

   A. 1000
   B. 1111
   C. 1001
   D. 1010

6. The quantity, 0111 = DCBA, is in binary-coded decimal equal to decimal

   A. 7
   B. 5
   C. 9
   D. 6

7. In which of the following choices are all of the IC chips either decoders or decoder-drivers?

   A. 7447, 7451, and 74150
   B. 7448, 7451, and 74160
   C. 7442, 7447, and 74154
   D. 7442, 7448, and 74150

8. Which of the following IC chips is a 4-line-to-10-line decoder?

   A. 7447
   B. 7451
   C. 74150
   D. 7442

9. In a decade sequencer, one requires a

   A. 74150 chip and a decade counter such as the 7490
   B. 74150 chip and a binary counter such as the 7493
   C. 7451 chip and a decoder such as the 7442
   D. 7442 chip and a 7490 chip

10. A demultiplexer is similar to a

    A. shift register
    B. decoder
    C. device that can select one of a number of inputs and pass the logic level on to the output
    D. data selector

11. When connected in the proper way, the 74150 and 74154 chips can serve as a

    A. sequencer
    B. simultaneous decoder/driver
    C. multiplexer/demultiplexer circuit
    D. programmable sequencer

12. The current that passes through a light-emitting diode (LED) should generally NOT exceed

    A. one ampere
    B. one milliampere
    C. 30 to 50 milliamperes
    D. 300 milliampere

13. When the anode of a LED is connected to +5 volts and the cathode is connected to ground, the LED will

    A. remain unlit
    B. become lit, although only slightly
    C. light up immediately, but it may become unlit owing to the lack of a current-limiting resistor
    D. burn out

14. One can construct a simple logic probe from a

    A. light-emitting diode, capacitor, and battery
    B. LED, transistor, and battery
    C. LED and resistor
    D. LED and capacitor

15. When a logic probe is constructed from a LED and other components, a transistor is *usually* employed to

    A. make the LED light a bit more brighter
    B. conserve power
    C. *decrease* the current required to light the lamp monitor circuit
    D. *decrease* the voltage across the LED

16. A typical J-K flip-flop can have the following inputs:

    A. Strobe, enable, count, clear, and present
    B. Clock, preset, J, K, and clear
    C. Clock, count, J, K, and clear
    D. Clock, J, K, clear, preset, Q, and Q

17. A flip-flop is a

    A. three state device
    B. two state device
    C. one state device
    D. either a one state or a two state depending upon the logic state appearing at the strobe input

18. With the aid of a single gate, a 74126 gate with three-state output can be converted into a 18.___

A. monostable multivibrator
B. bi-stable memory element
C. tri-stable memory element
D. none of the above

19. When J = 0 and K = 1 in a J-K flip-flop, 19.___

A. Q can go to or stay at logic 1, but cannot go to logic 0
B. Q can go to or stay at logic 0, but cannot go to logic 1
C. the flip-flop toggles
D. Q remains at its logic state; the clock has no effect

20. When present at the inputs or outputs of logic devices, the small circle o represents 20.___

A. that a positive clock pulse may be required to enable the device
B. that a positive leading edge may be required to enable the device
C. inversion
D. a shorthand form for an AND gate

21. The preset and clear inputs to a flip-flop 21.___

A. do not take precedence to the J-K inputs, but do take precedence to the clock input
B. do not take precedence to the clock input, but do take precedence to the J-K inputs
C. take precedence over all other inputs
D. none of the above

22. A typical read-only memory (ROM) IC chip has 22.___

A. memory cell select inputs, memory enable input, read/write select input, data inputs, and data outputs
B. data inputs, data outputs, memory enable input, and memory cell select inputs
C. memory enable input, memory cell select inputs, and data outputs
D. data inputs, data outputs, read/write select inputs, memory cell select input, and clock input

23. A typical random access memory (RAM) IC chip has 23.___

A. memory cell select inputs, memory enable input, read/write select input, data inputs, and data outputs
B. data inputs, data outputs, and memory cell select inputs
C. data outputs, memory cell select inputs, and memory enable input
D. data inputs, data outputs, read/write select input, memory cell select input, and clock input

24. Shift registers can 24.___

A. convert serial data into parallel data
B. convert parallel data into serial data
C. store both serial and parallel data
D. do all of the above, depending, of course, upon the nature of the specific shift register used

25. The 74194 shift register can

    A. parallel load
    B. shift right
    C. shift left
    D. all of the above

KEY (CORRECT ANSWERS)

1. C
2. D
3. B
4. C
5. B
6. A
7. C
8. D
9. D
10. C
11. C
12. C
13. C
14. C
15. C
16. B
17. B
18. D
19. B
20. C
21. C
22. C
23. D
24. D
25. D

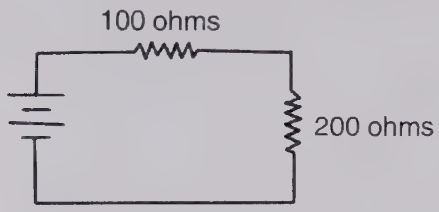
ELECTRO-MECHANICAL NOTES AND RESOURCES

TABLE OF CONTENTS

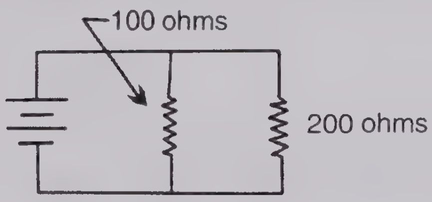
ELECTRO-MECHANICAL NOTES AND RESOURCES

I. BASIC ELECTRICITY

Resistance is measured in ohms, and its symbol is Ω. Resistance is additive in series circuits. This means that with two resistors in series as shown below, if one resistor is 100Ω's and the other 200Ω's, then the total resistance is 300Ω's.



Series circuit



Parallel circuit

Resistance in parallel is summed differently. In the figure shown above in the parallel circuit, if the 100 ohm resistor is considered to be R, and the 200 ohm resistor is R, the formula is:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}.$$

Derivation is as follows:

$$\frac{1}{R_1} = \left(\frac{1}{R_1} \times \frac{R_2}{R_2}\right) + \left(\frac{1}{R_2} \times \frac{R_1}{R_1}\right) = \frac{R_1}{R_1R_2} + \frac{R_1}{R_1R_2} = \frac{R_1 + R_2}{R_1R_2}$$

So, now we have:

$$\frac{1}{R_t} = \frac{R_1 + R_2}{R_1R_2}. \text{ Inversing, } \quad \frac{R_t}{1} = \frac{R_1R_2}{R_1 + R_2} = R_t$$

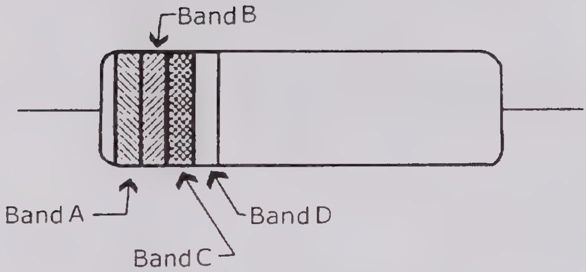
This derivation is for two resistors in parallel; for more resistors in parallel, the same derivation technique would be followed.

Given that all the resistors in a parallel circuit are of the same resistive value, the following is a short calculation of the total circuit resistance.

Take the resistive value of one of the resistors and divide it by the number of resistors in the parallel circuit. Assuming that 5 resistors are in parallel and each one is 500 ohms, to calculate the total circuit resistance, divide 500 by 5 and the result is 100 ohms.

An interesting aspect of resistance is that the inverse (1/R) is conduction, the ease with which electrons can flow through a given material, and is expressed in units of *mhos* with a symbol that is the same as the resistance symbol inverted.

The color codes for resistors are as follows:



Band A is the first digit of the value of the resistor.
Band B is the second digit of the value of the resistor.
Band C is the decimal multiplier.
Band D is the tolerance of the value of the resistor.

The colors and their values are:

COLOR	VALUE	COLOR	VALUE	TOLERANCE COLORS
BLACK	0	GREEN	5	
BROWN	1	BLUE	6	GOLD 5%
RED	2	VIOLET	7	SILVER 10%
ORANGE	3	GRAY	8	NO COLOR 20%
YELLOW	4	WHITE	9	

So, a resistor colored as:

1st band	violet
2nd band	green
3rd band	blue
4th band	silver

is computed as:

Violet Green Blue Silver

$$75 \times 10^{6} \text{ ohms} \pm 10\% \text{ or } 75 \text{ megohms} \pm 10\%$$

An easy way of remembering the sequence of the color codes above is to remember the following sentence and use the first letters of each word: *Bad Boys Race Our Young Girls Behind Victory Garden Walls.*

Ohms' Law

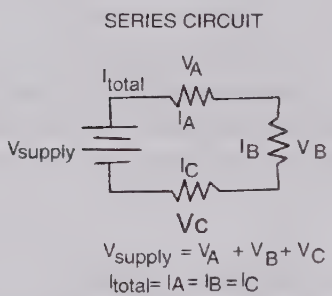
Ohm's law is the law that establishes the mathematical relationship of current, voltage, and resistance in a circuit. The formula is: E = IR, where E = the circuit or component voltage, I = the circuit or component current, and R = the circuit or component resistance.

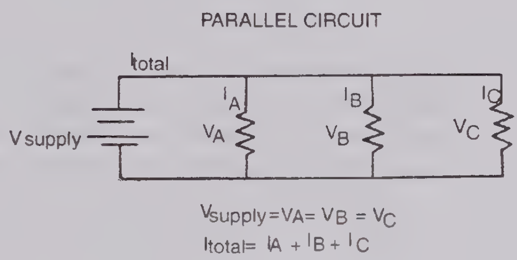
In the circuit shown below, we know E = 10 volts and I=5 ohms. Deriving the formula, we get I = E/R. So, I = 10/5 = 2 amps.

The power consumed by a component is equal to E x I. So, P = EI, and this calculated value is expressed in units of watts.

Kirchoff's Voltage Law

Kirchoff's voltage law states in technical terms that in a simple series circuit, as shown below, the algebraic sum of the voltages around the circuit is zero. Basically, this means that the supply voltage, Vsupply, is equal to VA + VB + VC, which are the voltage drops across the respective resistors in the circuit below. In the parallel circuit shown below, the voltages in each of the individual branches are equal to each other as well as equal to the total circuit voltage.





Kirchoff's Current Law

Kirchoff's current law states that at any junction of conductors in a circuit, the algebraic sum of the currents is zero. On a series circuit shown above, current is equal across each individual component as well as equal to the total circuit current. In a parallel circuit, the current across each individual branch when added is equal to the total circuit current, as in the parallel circuit shown above.

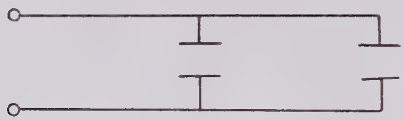
Inductors

Inductors are coils that oppose changes in current, which also store energy in a magnetic field. Induction is expressed in units of henries, and represented by an h. Inductance in series and parallel circuits is summed in the same manner as resistance. Inductors tend to block AC signals and pass DC voltages. An inductor's ability to oppose AC current is called inductive reactance. Inductive reactance is expressed in ohms just like resistance, but is represented by the symbol ZL, where Z means impedance and L added specifies inductive reactance or impedance. The impedance symbol Ω should not be confused with the resistive symbol, which is the same. The formula for inductive reactance is: $XL = 2\pi fL$, where $\pi = 3.14$, f = the frequency of the AC signal to be used, and L = the inductance in henries. The schematic symbol for an inductor is 

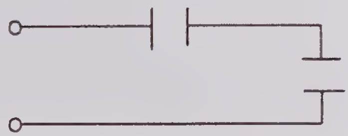
Adding two lines on the top of the symbol means that it is an iron core filled inductor. Since they have a magnetic field, they are used in transformers and electromagnetic switches.

Capacitors

Capacitors consist basically of two metal plates in parallel separated by an insulator (dielectric). Capacitors have the ability to store a charge in an electrostatic field between its two plates. This charge is dependent upon two things, the capacitance of the circuit and the difference in the potential of the circuit. The capacitance of a capacitor is measured in farads, and is depicted by the letter C. Capacitance is summed in a manner that is exactly opposite to that of resistors, since it is directly summed when in parallel as shown below.



Capacitors in parallel



Capacitors in series

In the parallel circuit shown above, if one of the capacitors is 1 farad and the other is 2 farads, then total circuit capacitance is 3 farads. Capacitance of such a high value is rare and usually limited to industrial use. More realistic values would be in the microfarad range. When capacitors are in series as shown above, they are added, as are resistors in parallel. So, the formula would be: $Ct= \dfrac{C_1C_2}{C_1+C_2}$

As with inductors, capacitors are also measured by the opposition that they may give to AC current flow, which is called capacitive reactance. Capacitive reactance, X_C, is expressed also in units of ohms, and its formula is:

$$X_C = \frac{1}{2\Pi fC}$$

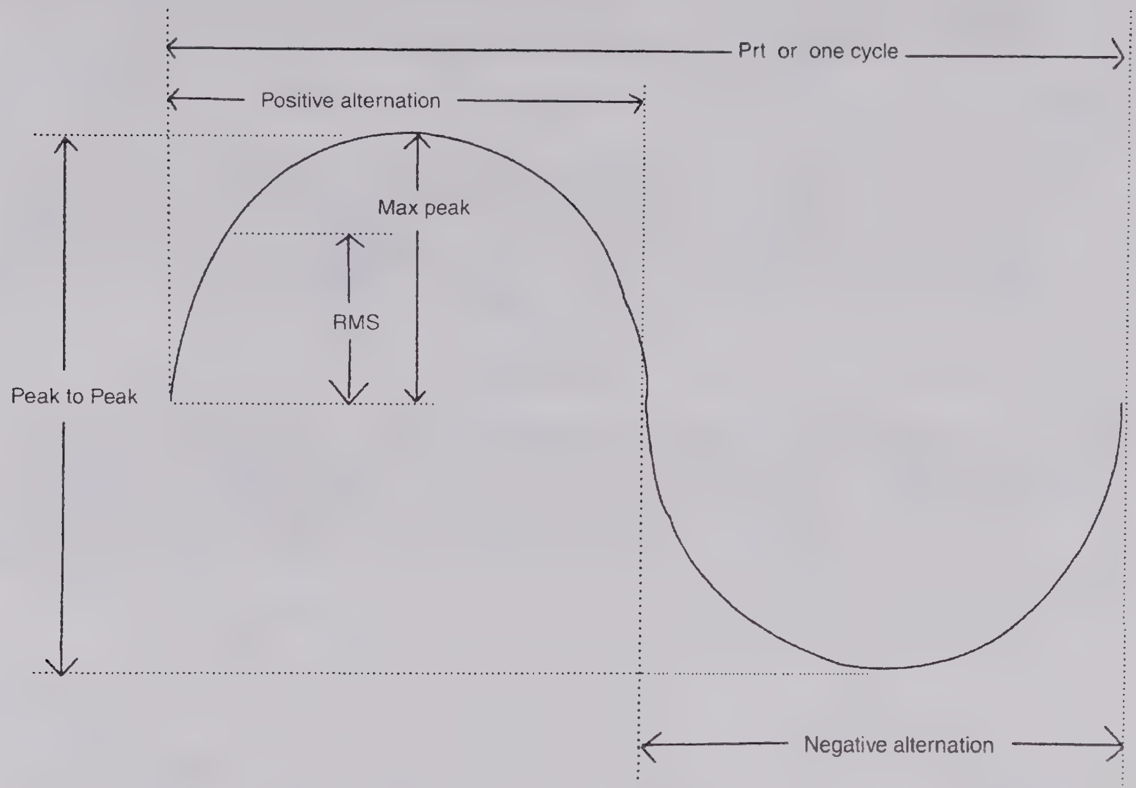
where f = the frequency in hertz of the AC signal, and C = the capacitance, in farads. Electrolytic capacitors are polarized, which means that they must be placed in circuits with polarity considerations.

AC Cycles

The five main forms of AC signals are sawtooth, sinusoidal, square, rectangular, and trapezoidal waveforms.

Sawtooth waveform Sinusoidal waveform Square waveform Rectangular wavefrom Trapazoidal waveform

There are also parts of sinewaves that are of interest.



The RMS value (root mean square) is the same as the effective value, which is the value of an AC signal that has the same power or heating effect as a DC voltage. With sinusoidal waveforms, this value is equal to .707 times the AC voltage peak.

The average value is the value of an AC signal of a positive alternation and in a sinusoidal waveform is equal to .637 times the maximum voltage or peak.

Magnetism

The basic properties of magnetism are permeability, reluctance, and retentivity.

Permeability is the property of the ease with which a metal will allow magnetic lines of flux to pass through it.

Reluctance is a property of a metal that opposes lines of flux going through it.

Retentivity is the ability of a magnetized metal to stay magnetized.

Permanent magnets have high retentivity. Steel has high retentivity, low permeability, and high reluctance. Soft iron has low retentivity, high permeability, and low reluctance.

When a wire has current passing through it, the wire will have an electromagnetic field around it. The left hand rule can be used to determine the direction of the electro-

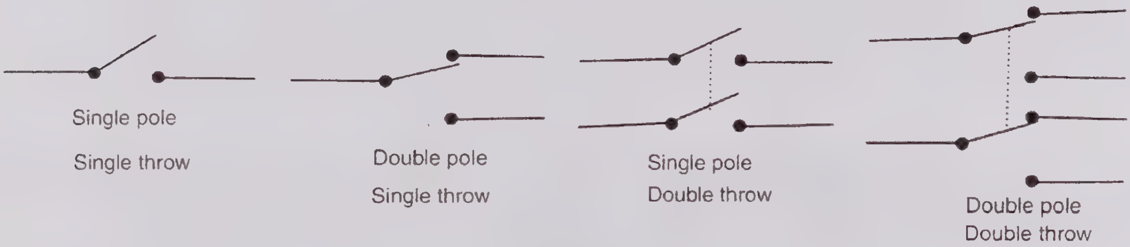
magnetic lines. To do this, place your left hand with fingers wrapped around the wire and your thumb pointed in the direction of current flow. The direction in which your fingers are pointing is the direction of the electromagnetic lines of flux.

Relays

The three types of relays are power relays, control relays, and sensing relays. Power relays control high voltages going to circuits such as motors. Control relays are used to energize and de-energize other relays and associated circuitry. Sensing relays are used to detect such items as over or under, current or voltages. When sensed by the sensing relay, power sources will be disconnected.

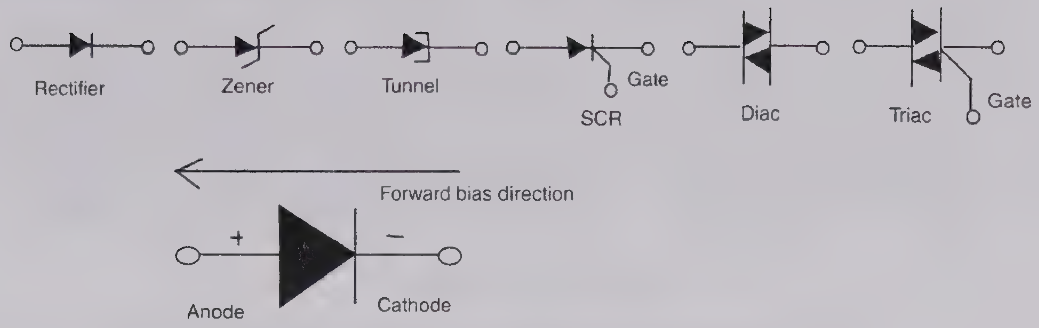
Switches

The various types of switches are identified by the number of poles, throws, and positions that they have. The number of *poles* that a switch has indicates the number of terminals through which voltages may enter the switch. The number of *throws* refers to the number of circuits that could be completed or disconnected by each blade or contacter. The number of *positions* indicates the number of different places that the toggle of the switch can be placed in.
The four kinds of switches are shown below.



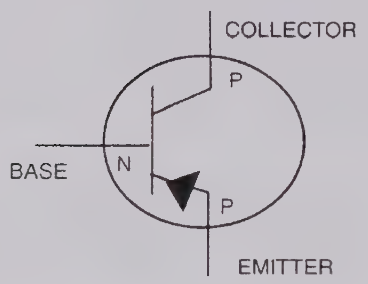
Diodes

As its name implies, a simple rectifier diode is used for signal rectification. The schematic symbol is shown below. Zener diodes are designed for specific reverse breakdown voltages; and since they keep the voltage across the diode constant, they are used for voltage regulation. Tunnel diodes will give negative resistance for specific ranges of forward bias voltages. Because of this phenomenon, tunnel diodes are used as amplifiers or oscillators. Silicon controlled rectifiers (SCR) are triggered diodes. These are used to control AC voltages on one particular half cycle. Diacs work on both sides of the cycles of an AC signal. Triacs are gated diacs. Basically, SCRs, diacs, and triacs are used to pick out desired portions of AC signals.

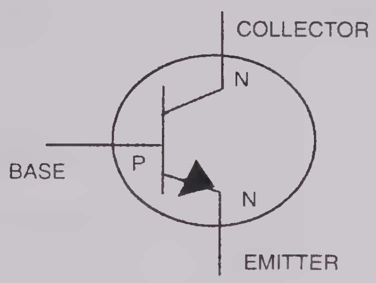


Transistors

Transistors are solid state devices that can act as amplifiers or switches. They are classified as bipolar and field-effect transistors. The bipolar transistor allows current flow in either direction. The two types of bipolar transistors are PNP and NPN transistors, which are shown below.



PNP transistor



NPN transistor

When used strictly as a switch, the PNP transistor requires a negative input signal on the base to turn it on or conduct. Conversely, the NPN transistor requires a positive signal on the base to turn it on.

Bipolar transistors are not only used as switches and have several configurations. The different transistor configurations and their respective traits are shown below:

<u>BEG</u>
VPI
ABG
LMH
HML
IOI

The <u>first</u> line is the type of configuration, i.e., common base, emitter, or collector. The particular transistor's configuration traits are shown vertically below the transistor. Line <u>two</u> shows electrical gains (voltage, power, or current). Line <u>three</u> shows the type of gain (alpha, beta, or gamma). Line <u>four</u> shows the input impedance of the configuration (low, medium, or high). Line <u>five</u> shows the output impedance (high, medium, or low).

Line six shows the output signal phase relationship with the input (in-phase or out-of-phase).

There are two types of field effect transistors (FET) - JFETs and MOSFETs. JFETs stand for junction field transistors and control large voltages with very small inputs and, therefore, can be used as amplifiers. MOSFETs stands for metal-oxide-semiconductor field effect transistors and have a higher input impedance and can use even smaller signals. They are also smaller and are configured by the thousands to form chips.

Soldering

Electrical connections are joined by soldering. Soldering requires a high heat source and an alloy that melts at a relatively low temperature when compared to other metals. The basic soldering technique is to first heat the joint to be soldered with a soldering device and then place the solder directly onto the joint with the soldering device still in contact. Allow the solder to melt and flow onto the joint surface covering the joint area. Once this occurs, remove solder and device, allowing to cool without any movement of the joint area. After the solder hardens, inspect the solder joint. The joint should look smooth, bright, and shiny, with the surface area of the joint smoothly covered. If the solder has the appearance of being partially balled up instead of a smooth semi-flat flow, it is called a *cold solder* joint. A possible cause of a cold solder joint might be wrongly applying the solder to the solder device and then dropping onto the area to be soldered. If the solder joint is not shiny but dull and gray instead, then the connection was probably moved prior to the solder hardening completely.

Solder is an alloy usually made up of various ratios and combinations of tin and lead. Some that are resin filled are also called flux. Soldering fluxes are used to de-oxide surfaces that are being soldered. One type of flux is acid-core resin, which is very corrosive to electrical connections and should be avoided.

Soldering devices come in various sizes, depending on the job required to be done. One of the most delicate of soldering jobs, soldering components with very small connections onto printed circuit boards, is usually done by pencil irons. These miniature irons are ideal for providing low heat to small areas. Soldering jobs that require more heat use items such as solder guns. These produce high heat and heat up very quickly.

The types of solder tips most commonly used in electrical work are made of copper or copper alloys, since copper has high heat conductivity and good tinning quality. The tinning of a soldering tip increases heat transfer/conductivity to the area to be soldered and also reduces scaling of the solder tip. Tinning consists of getting a good layer of solder on the working surface of the copper tip. Cleaning tips that become dirty or discolored requires dipping the tip in water while hot, and quickly removing it or wiping with a damp sponge or towel.

II. COMPUTERS

The 5 major components of a computer are input, storage, control unit, arithmetic and “logic unit, and output. The input device allows information such as data and commands or instructions to be fed into the computer system. The most common type of

input device is the keyboard. Other input devices are magnetic and optical readers. <u>Storage</u> devices are used to store memory, such as instructions or data until they are needed. Memory is stored in bits, which is the most basic element of binary numbers, a 1 or 0. Bytes are groups of eight bits. A nibble is half of a byte. The <u>control unit</u> coordinates the operations of the entire computer. It interprets programs and issues instructions to accomplish the program. The <u>output</u> device communicates the progress or results of a program used in the computer to the operator/user. The devices range from monitor screens to high speed printers.

Numbering Systems

Computers and associated circuitry use several numbering systems that have different bases. We are all familiar with base 10 numbering system. This is the system we use in everyday life. In this system, each decimal/digit place represents a value of 10, whether it is the first digit to the left of the decimal point, which is a 10 to the 0 power or one's. The second digit to the left represents the number of 10's and the third represents the number of 100's.

The other base sytems work in the same fashion with their own respective bases. The other base systems used are base 2 (binary), base 8 (octal), and base 16 (hexadecimal). It is easy to convert from one system to another.

	5th digit	4th digit	3rd digit	2nd digit	1st digit
Base 10	10^4	10^3	10^2	10^1	10^0
Base 2	2^4	2^3	2^2	2^1	2^0
Base 8	8^4	8^3	8^2	8^1	8^0
Base 16	16^4	16^3	16^2	16^1	16^0

The largest number in base 10 is a 9, for base 2 it is 1, for base 8 it is 7, for base 16 it is 15. The numbers for base 16 greater than 9 are expressed by letters, i.e., 10 = A, 11 = B, 12 = C, 13 = D, 14 = E, and 15 = F.

The following is a conversion of the base 16 number to the other bases. The number will be $2B7_{16}$

$$\begin{array}{r} 2 \\ \times 16 \\ \hline 32 \end{array} \qquad \begin{array}{c} B^{*} \\ + \\ 32 \\ \hline 43 \\ \times \\ \underline{16} \\ 688 \end{array} \qquad \begin{array}{r} 7 \\ + \\ 688 \\ \hline 695 \end{array} \qquad \text{Base 16}$$

So $2B7_{16} = 695_{10}$

*B = 11

The procedure for calculating is to start with the most significant digit and multiply it by the value base used. In this case, the most significant digit is a 2 and the base value is 16. Next, take the result of the multiplication and add this to the next lower digit and then multiply by the digit place value. This was (32+11) x 16 = 688. This procedure continues until the least significant digit is reached. At this point, just add the accumulated value so far with the last digit.

This same process is used for converting any other number of a different base to base 10 number, using the respective base values.

To convert a base 10 number to its base 16 (or any base), the process is as follows: First, the base 10 number is divided by the base number of the base system it is to be converted to. To reconvert 695 base 10 back to base 16, 695/16 = 43 with a remainder of 7. The remainder (7) is the least significant digit of the new base number. Next, 43/16 = 2 with a remainder of 11. 11 is the next digit because we are going to base 16, 11 = B. Since it is less than the base number (16), 2 becomes the most significant digit. So, the converted number is 2B7 base 16.

To convert the base 10 number to base 8, 695/8 = 86 with a remainder of 7, which will be the least significant digit. Now, 86/8 = 10 with a remainder of 6, which is the next digit. Finally, 10/8 = 1 with a remainder of 2, which is the next digit. 1 is left as the most significant digit. So, 695 base 10 = 1267 base 8.

We can reverse this to see if it is correct. Multiply the most significant digit 1 by 8. 1x8=8. Add this to the next digit and multiply by 8, (8+2) x 8 = 80. Add the result to the next digit and multiply by 8, (80+6) x 8 = 688. Now, add the result to the last (least significant) digit, 688 + 7 = 695. So, 695 base 10 does = 1267 base 8.

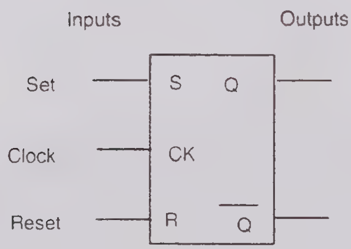
Performing base 2 calculations is just as simple. Take 21 base 10 and convert to base 2. 21/2 = 10 with a remainder of 1, which is the least significant digit. 10/2 = 5 with a remainder of 0, which will be the next digit. 5/2= 2 with a remainder of 1, the next digit. 2/2 = 1 with a remainder of 0, the next digit. The remaining number will be the next most significant digit. So, 23 base 10 = 10101 base 2.

Reverse this to check: 1x2=2. (2+0) x 2 = 4. (4+1) x 2 = 10. (10+0) x 2 = 20. (20+1) = 21. So, 23 base 10 does equal 10101 base 2.

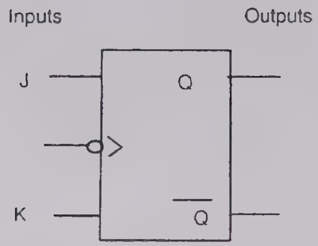
Flip Flops

Flip flops have one of two stable states. They change states by receiving input pulses. The reset-set flip flop (RS FF) is one of the most basic forms of flip flops made by interconnecting two NAND gates.

RS Flip flop



Condition	Clock Pulse			Q	$\overline{Q}$
Disabled		0	0	No Change	
Set		1	0	1	0
Reset		0	1	0	1
Hold		1	1	1	1

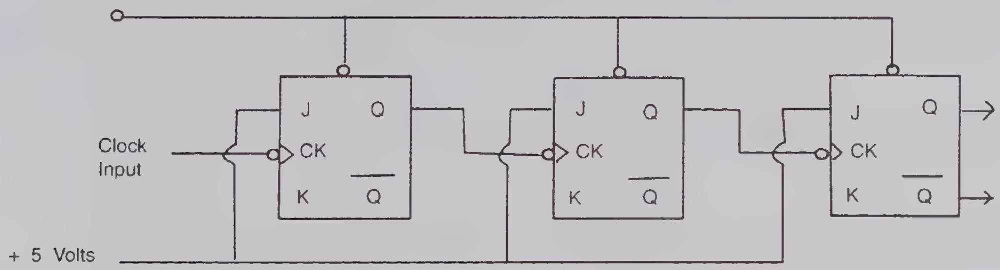


J-K Flip flop

Condition	Clock Pulse			Q	$\overline{Q}$
Hold		0	0	NO Change	
Set		1	0	1	0
Reset		0	1	0	1
Toggle		1	1	Change to Opposite state	

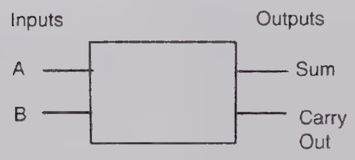
A flip flop with a clock input is called a synchronous device; without a clock input it is called an asynchronous device.

The most common type of flip flop is the J-K flop flip (shown on the previous page). The J + K inputs are data inputs. The arrowhead > at the clock input means that the flip flop is edge triggered. The bubble 0 means that the flip flop is negative edge triggered. Flip flops can be put together to make counters such as:

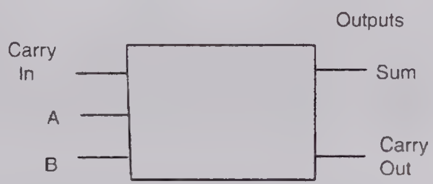


Shift registers also use flip flops in which data is loaded serially (one bit at a time). Once the FF's are loaded with data, they can be shifted left or right (depending upon how they are wired), by clock pulses. Shifting the data to the left or right will either divide by 2 or multiply by 2, depending on which FF has the least significant digit.

The following represent adders which perform arithmetic operations:



Half adder



Full adder

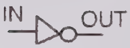
Half adders add binary numbers like the full adder, but do not consider previous carry inputs.

The significance of flip flops is that they can be grouped together to form units of memory, such as RAMs, ROMs, PROMs, and EPROMs. RAM (random access memory)

is volatile memory, meaning that when power is turned off, the stored memory is lost. RAM is considered a read-write memory, meaning that you can read data from or write data into the memory. ROM (read-only memory) is non-volatile, meaning that when power is turned off, memory is not lost. ROMs are permanently programmed by the manufacturer and is often called firmware. PROMs (programmable read-only memory) are special ROMs designed to allow the user to program the ROM. EPROMs (erasable programmable read-only memory) are also special ROMs that allow the user to program memories and erase the programs.

Logic Gates

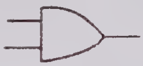
Logic gates use binary inputs. In positive logic, a 1 is a high input and a 0 is a low input. In negative logic, a 1 is a low input and a 0 is a high input.



Inverter

TRUTH TABLE

IN	OUT
1	0
0	1



And gate

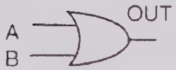
TRUTH TABLE

A_{IN}	B_{IN}	OUT
0	0	0
0	1	0
1	0	0
1	1	1

Nand gate

TRUTH TABLE

A_{IN}	B_{IN}	OUT
0	0	1
0	1	1
1	0	1
1	1	0



Or gate

TRUTH TABLE

A_{IN}	B_{IN}	OUT
0	0	0
0	1	1
1	0	1
1	1	1

Nor gate

TRUTH TABLE

A_{IN}	B_{IN}	OUT
0	0	1
0	1	0
1	0	0
1	1	0

Exclusive or gate

TRUTH TABLE

A_{IN}	B_{IN}	OUT
0	0	0
0	1	1
1	0	1
1	1	0

Exclusive nor gate

TRUTH TABLE

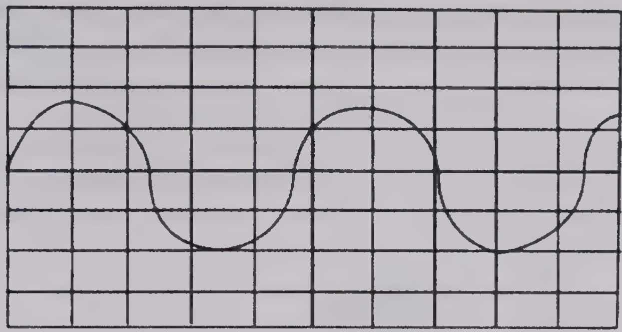
A_{IN}	B_{IN}	OUT
0	0	1
0	1	0
1	0	0
1	1	1

III. OSCILLOSCOPES

Oscilloscopes are used to display instantaneous voltage waveforms in graphic form. The display screen is set up and divided vertically and horizontally in 1 cm divisions. There are 8 vertical divisions in which waveform amplitude is displayed and 10 horizontal divisions in which the time of the wavelength is displayed.

The VOLTS/DIV knob allows the user to select the waveform voltage amplitude in each vertical division to be displayed. The SEC/DIV knob allows the user to select the sweep speed of the waveform in each horizontal division to be displayed.

Proper use of the oscilloscope requires the ability to analyze displayed waveforms by observing the number of divisions a cycle of a given waveform covers both vertically and horizontally.



In the waveform shown above, the VOLT/DIV knob is set on 5 volts/div and the SEC/DIV knob is set to 1 msec/div.

Count the number of divisions covered vertically by the waveform, which is 3 1/2 divisions. To get the actual peak-to-peak amplitude of the sinewave, perform the following calculation: 3 1/2 divisions x 5 volts/division = 17.5 volts peak to peak.

Now count the number of divisions covered horizontally by one complete cycle of the waveform, which in this case is 4 1/2 divisions. To find the PRT (pulse repetition time), perform the following calculation: 4 1/2 divisions x .001 sec/division = .0045 seconds. .0045 seconds x msec/.001 sec = 4.5 msec for the PRT.

To find the frequency, simply invert the PRT: Frequency = 1/PRT = 1/.0045 sec = 222.22 cycles/sec or hertz.

The same process could be reversed to find the settings to use on an oscilloscope when you know the amplitude and frequency of a given waveform/signal that you would like to view on the oscilloscope.

Meters

The following are the basics of measuring meters: Always measure current *in series* with the circuit to be measured and always measure voltage in parallel with the circuit.

When performing resistance measurements, always ensure that the component or circuit has no voltage on it and consider whether a specific component may need to be isolated from the rest of the circuit so that the resistance measurement does not follow an alternate path. This can be accomplished by removing one of the *electrical* legs of the component from the circuit. When unsure of the amount of voltage on a circuit to be measured, start with the highest meter setting or range.

When using analog or needle deflection type meters, ensure that you have the proper polarity of leads when checking for DC voltages. One of the most popular analog type multimeters used is the Simpson 260. For copyright reasons, a copy of the meter cannot be given but here are some tips that will work using any analog multimeter. When performing DC measurements, look at the range setting that you have the meter set up for, and find the same corresponding scale on the meter face for proper readings. When performing resistance measurements, read the resistance value on the resistance scale

where the needle is deflected to and then multiply this by the resistance range setting. An example of this is with the needle setting on a value of 8 on the resistance scale and the range knob on *RX1000,* then the value of resistance is 8000 ohms.

IV. SCIENTIFIC NOTATION

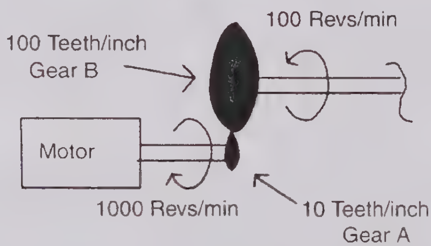
Scientific notation is a way of expressing large numbers. For example, 100,000,000 ohms could be written as 100 x 10^6 ohms or 100 megohms. Other prefixes like meg are listed below.

FACTOR	PREFIX	SYMBOL	FACTOR	PREFIX	SYMBOL
10^{12}	tera	T	10^{-2}	centi	c
10^9	giga	G	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	μ
10^3	kilo	K	10^{-9}	nano	n
10^2	hecto	h	10^{-12}	pico	p
10^1	deka	da	10^{-15}	femto	f
10^{-1}	deci	d	10^{-18}	atto	a

V. GEARS

Gears are wheels with teeth that are used to transmit mechanical motion from one point to another. The usual configuration is that of two gears meshed together. In this configuration, the larger gear is simply called a *gear* and the smaller gear is called a *pinion.* If the pinion drives the gear, the system is called a speed reducer. If the gear drives the pinion, then the system is called a speed increaser.

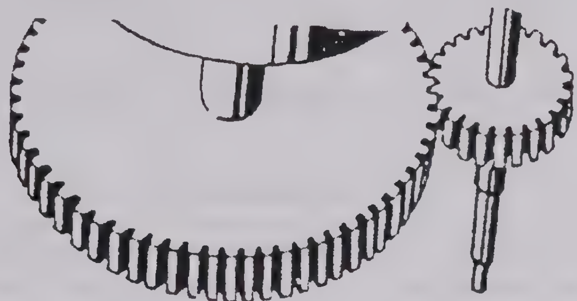
When gears are used in increasing or decreasing speeds, they are configured in gear ratios. This allows specific speed changes. For example, for a gear to turn 100 revolutions per minute, if the shaft of the driving motor turns at 1000 revolutions per minute, to achieve the desired speed, it is necessary to use a reducer configuration. This is accomplished by changing the gear ratios. Since gears are made with a certain number of teeth per inch, reducing the number of teeth per inch on the gear attached to the motor shaft to one-tenth of that of the other gear that is being driven would reduce the speed of the driving shaft from 1000 revolutions per minute to 100 revolutions per minute on the driven shaft.



The basic formula for calculating the relationship between the gears and their respective speeds is: Revs/min(gear A) x Teeth/inch (gear A) = Revs/min(gear B) x Teeth/inch(gear B).

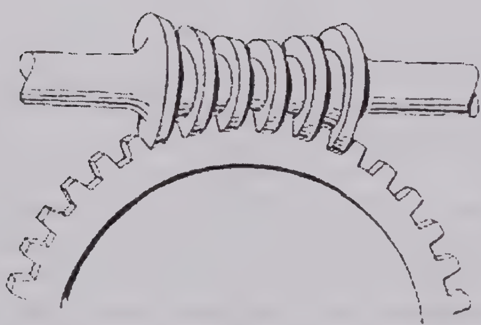
When two gears mesh, they turn in opposite directions. Adding a third gear called an idler gear and placing it in-between the two gears will allow them to turn in the same direction. There are four basic types of gear configurations, and they are spur, worm, helical/herringbone, and bevel gears.

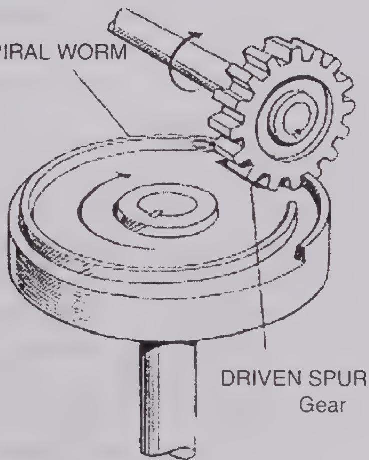
Spur gears are the most common type, having straight teeth. They are used to transmit power between two parallel shafts.



TYPICAL SPUR GEAR

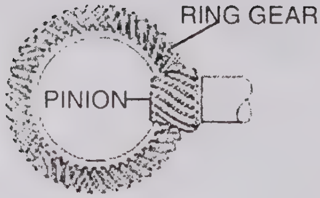
Worm gears having helical teeth are used to transmit power between two shafts whose axis intersect, but not in the same plane. This is probably the most common method of speed reduction, especially in conveyers because the speed of a very fast rotating motor can be greatly reduced.



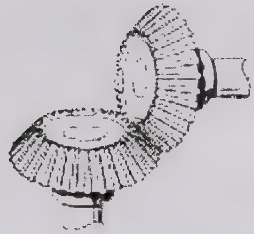


A TYPICAL WORM GEAR SET-UP

Helical/herringbone gears have spiral teeth which allows them to transmit power between two shafts at any angle.



A TYPICAL
HELICAL GEAR



A TYPICAL
BEVELED SPUR GEAR

Bevel gears are shaped like sections of cones and used to transmit power between shafts whose axis intersect.

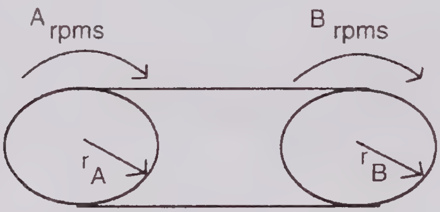
Pulleys

Pulleys are wheels used to transmit power such as pulleys used to transmit power from a motor to drive the roller of a conveyer belt. The main feature of a pulley is its ability to change speeds or revolutions per minute. When a pulley drives another pulley with a smaller diameter, the rpms of the second pulley will be greater. This results in a speed increase similar to that in gear systems.

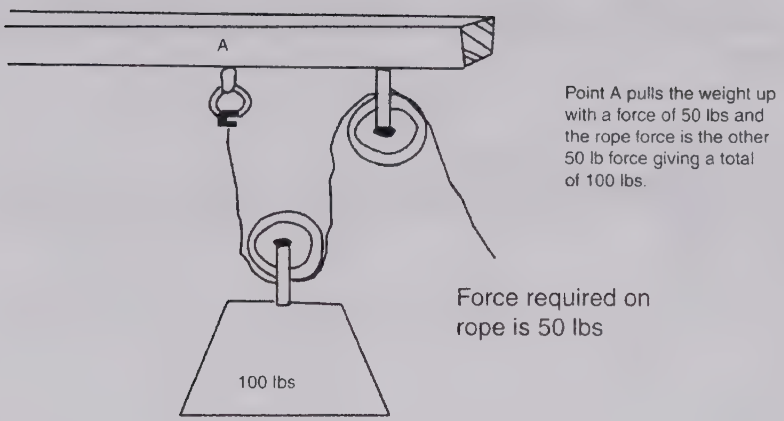
A formula for calculating the circumference around a pulley is: $C = 2\pi r$, where r is the radius of the pulley, and $\pi = 3.14$. Through a series of derivations, the relationship of respective rpms between two connected pulleys is as follows.

Arpms = Brpms x rB/rA where:

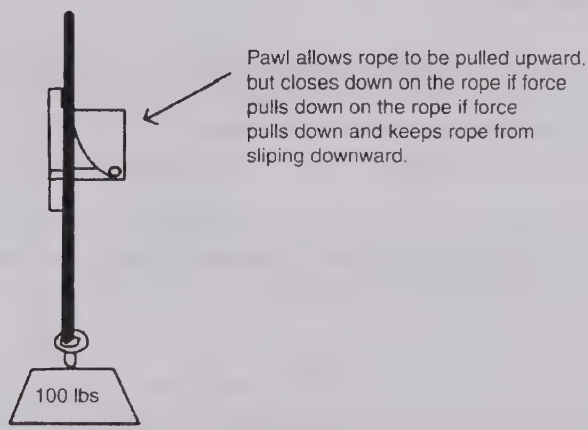
Arpms = revolutions per minute of pulley A
Brpms = revolutions per minute of pulley B
rB = radius of pulley B
rA = radius of pulley A



Another use of pulleys is compounding. Compound bows used for archery take advantage of the physics involved in compounding to allow archers to draw bows at high weight pulls with relative ease. For example, to pull up a 100 lb. weight, instead of having to pull with a force of 100 lbs., pulleys can be used to lessen the force required.



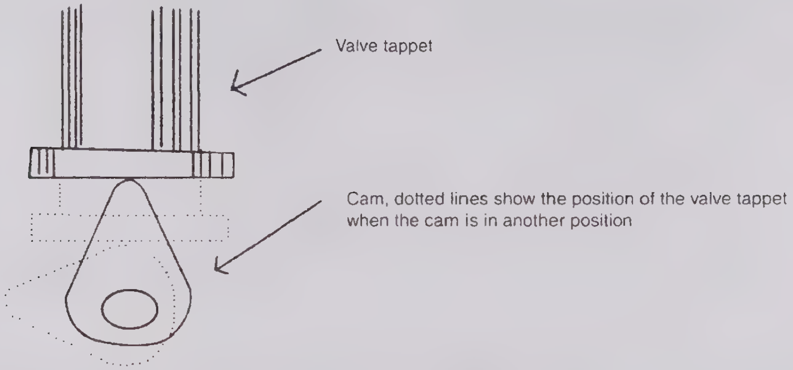
A pawl is a device used to allow a wheel to turn in one direction and lock the wheel from turning in the other direction. Pawls are commonly found in winching or come-along set-ups.



Special coupling is required in power transmissions in order to get mechanical power from one point to another. There are four general types of coupling. The first type is rigid coupling and is rarely used because the shafts must be exactly parallel and, therefore, do not allow for misalignment. The second is flexible coupling which allows for some misalignment although excessive misalignment increases wear. The third type is chain coupling which has been mostly replaced by flexible coupling which requires the most maintenance of all couplings. The last is fluid coupling which uses steel shot as a flow charge. This allows the motor to pick up loads gradually.

Chains should be mounted horizontally or not more than 60 degrees off the horizontal plane. They do allow for the most misalignment. Hook-shaped sprocket teeth show excessive wear. Misalignment may be identified by inspecting for wear on the sides of teeth on the inner surface of roller link plates. The chain sag should not be greater than 2% of the distances from the sprockets, which is 1/4 inch per foot.

<u>A cam</u> is a device connected to a rotating shaft used to convert rotary motion into reciprocal motion.



<u>Lubricants</u>

Lubrication materials occur in many mediums. Three that will be discussed here are oils, greases, and solids.

Multigrade oils are the most versatile of the oil types. They have additives that allow them to be used in a wide range of temperatures. For example, in an oil labeled 10 w/30, 10 is the SAE viscosity number at 0 degrees Fahrenheit, and the SAE viscosity number at 210 degrees Fahrenheit is 30.

Greases are used in the lubrication of ball or idler bearing systems. Generally speaking, greases are oils that have had thickening agents or *soaps* added. The different kinds of greases are graded from 000, which is a *semi-fluid,* to 6 which is described as being very stiff or thick.

Another type of lubricant is solids. The most common type of solid lubricant is graphite. Another type is molybdenumdisulphide. Solid lubricants are extremely useful as anti-seize compounds to protect rubbing surfaces under high pressures and temperatures from metal pick-up.

BASIC FUNDAMENTALS OF
SIGNAL GENERATORS AND OSCILLATORS
AND
FREQUENCY MEASUREMENT

CONTENTS

BASIC FUNDAMENTALS OF SIGNAL GENERATORS AND OSCILLATORS AND FREQUENCY MEASUREMENT

I. SIGNAL GENERATORS AND OSCILLATORS

1. Signal Generator

A signal generator is an instrument which generates an a-c signal suitable for test purposes. Actually, it is a miniature radio transmitter and can be made to generate signals for any desired frequency.

a. USES. These generated signals can be modulated or unmodulated and are used for:

(1) *Receiver alinement*: Adjusting the i-f (intermediate frequency) and r-f tuned circuits to their correct frequencies.

(2) *Receiver performance testing*: Checking receiver sensitivity and a-f (audio-frequency) response, selectivity, and signal-to-noise ratio.

(3) *Receiver servicing*: Trouble shooting a defective receiver. The defective stage often is found by *signal substitution* or *signal tracing*.

b. TYPES.

(1) When signal generators are classified according to *frequency,* they can be either a-f or r-f generators. A-f generators usually are called *audio oscillators*. They are capable of producing signals in the audio range from 20 to 20,000 cps. R-f generators generate signals over any specified range of frequencies above 20,000 cps, but no single generator will cover all of the r-f ranges used in radio and radar. Different r-f generators are available, each covering a specified frequency range, and many of these also have an audio output available. The audio output can be variable over part or all of the audio range, or can be a fixed frequency, usually 400 cps.

(2) The classification of r-f and a-f signal generators also can be subdivided according to their signal output. Audio oscillators can have either a sine-wave or a square-wave output. R-f signal generators can have either pure r-f, a-m (amplitude-modulated), f-m (frequency-modulated) or pulse-modulated output. In a-m generators, an audio signal is mixed with the radio frequency and the r-f *amplitude* varies with the amplitude of the audio signal. In f-m generators, the radio frequency is varied in *frequency* at a rate determined by the amplitude of the audio signal. In pulse modulation no audio signal as such is mixed with the radio frequency, which is interrupted, however, usually at an audio rate, a number of times per second.

2. Principles of Tuned Circuit

All signal generators have an *oscillator* stage and, therefore, a review of oscillator fundamentals is offered before a discussion of typical signal generators.

a. TUNING FORK AS RESONANT CIRCUIT.

(1) Musicians sometimes use a tuning fork (fig. 1) to obtain a sound of a certain frequency. When this is struck, it vibrates against the air molecules, displacing the air around it at a frequency determined by its size. The waves of air strike the eardrums of the listener, causing them to vibrate at the same frequency, and produce the sensation of sound.

(2) The energy that has been imparted to the fork by the force of the original blow is used up gradually in moving

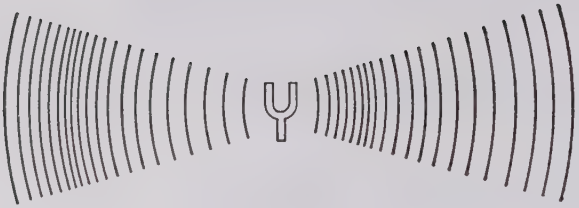


Figure **1**. *Tuning fork produces signal when struck, by vibrating at its resonant frequency.*

the branches of the fork back and forth. The gradual decrease of vibrations after tuning fork is struck is called *damping*.

b. ELECTRICAL RESONANCE.

(1) Electrical circuits also will produce vibrations if given an *electrical* tap, producing signals at a frequency depending on their physical characteristics. This is the resonant frequency of the circuit (A, fig. **2**).

(2) The inductor and capacitor act electrically as a tuning fork does mechanically. A tuning fork, when tapped, starts vibrating mechanically. An electrical tap applied to the coil and capacitor sets them vibrating electrically. The electrical tap can be supplied by connecting the circuit across a battery with a switch in series, as in B. When the switch is closed for an instant, and then opened, an electrical vibration or a-c signal is produced for a time.

(3) The coil and capacitor together comprise a circuit which is resonant at a frequency determined by the values of L and C, L being the inductance of the coil and C the capacitance of the capacitor. When the circuit is excited, it vibrates, or oscillates, at a frequency equal to $1/2\pi\sqrt{LC}$.

c. FACTORS GOVERNING FREQUENCY AND DAMPING.

(1) If the capacitance is large, it accumulates a large charge when the switch is closed and takes a *long time* to discharge. Therefore, the frequency of oscillation is comparatively low. If the capacitance is small, it accumulates a smaller charge and the capacitor discharges *faster*. Therefore, the frequency of oscillation is higher. When the coil has a large inductance, the capacitor takes more time to discharge through the coil, because of the greater opposition to current flow. The greater the value of either L or C, the lower the frequency will be; the smaller are L and C, the higher the frequency.

(2) The more resistance in the coil, the more the oscillations are damped, and the faster they fall to zero. When the coil has a low resistance, less damping takes place, and the oscillations continue for a longer time before they die out.

3. Basic Oscillator Operation

a. DEVELOPMENT OF OSCILLATOR CIRCUIT. It is possible to produce undamped or continuous oscillations in the tuned circuit (B, fig. **2**) if

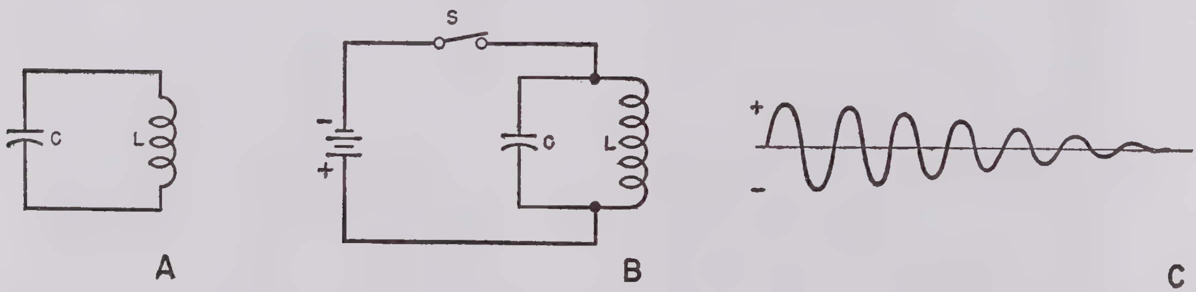


Figure **2**. *Electrical resonance.*

the battery switch is opened and closed rapidly every cycle, or even every other cycle. This gives the tuned circuit an electrical tap at the right instant, sustains the oscillations, and prevents them from damping out. An oscillator using an amplifier tube provides a regular tap (feedback) for the tuned circuit and generates a continuous, undamped a-c voltage at a frequency determined by the inductance and capacitance of the tuned circuit.

b. TYPICAL SELF-EXCITED OSCILLATOR OPERATION.

(1) Figure 3 shows a *self-excited* oscillator circuit, so-named because it requires no external signal to start or maintain oscillations. Because the tuned circuit is in the grid of the tube, it is called a *tuned-grid* oscillator. When the switch is turned on, current starts to flow in the plate circuit of the tube and passes through the primary of transformer T_1. Current through the primary causes magnetic lines of force to cut across the secondary, inducing a voltage in it.

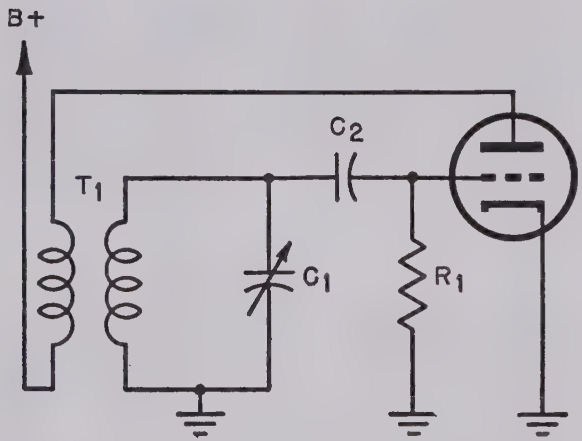


Figure 3 *Tuned-grid oscillator.*

(2) When the voltage induced in the secondary is positive in respect to ground, grid current flows and starts to charge the tuning capacitor C_1. The grid of the tube is positive in respect to the cathode, and the plate current increases. Because more plate current flows through the primary of T_1, the tickler coil, more lines of force are cutting across the secondary. This induces a larger voltage in the secondary and increases the current through the tube until it reaches the point of saturation. Saturation occurs when the current flow to the plate is maximum and no further increase in plate current can result.

(3) When the tube reaches saturation, the plate current neither increases nor decreases, and the lines of force around the tickler coil become stationary. Since no lines of force cut across the secondary, no voltage is induced, and the charged tuning capacitor starts to discharge through the coil.

(4) As the voltage across the tuning capacitor decreases, the voltage of the grid becomes negative in respect to the cathode. When the voltage on the control grid becomes sufficiently negative, current through the tube is cut off and no current flows in the plate circuit. The tuning capacitor discharges, and the voltage across the capacitor drops to zero. The lines of force surrounding the secondary of T_1 collapse and cause the polarity across the secondary to become negative in respect to ground. This voltage increases, and the tube remains cut off during the entire negative half-cycle of oscillation in the tuned circuit.

(5) The tuned circuit voltage then goes to maximum negative, back to zero, and starts to go to positive. As the tuned circuit voltage becomes more positive, it bucks the discharge of C_2 through R_1, and the voltage across R_1 decreases.

(6) There comes a point when the voltage between the grid and cathode decreases so that it is not enough to keep the tube cut off. The tube starts to conduct. The primary (tickler) feeds back a voltage to the secondary. The secondary, which is already a generator because it was charging the capacitor, gets a further boost or kick from

the lines of force of the tickler coil. The tuning capacitor is, therefore, charged a little more than it otherwise would be. The sequence then repeats itself, generating oscillations at a frequency determined by L and C.

4. Crystal Oscillator

a. CRYSTALS AND PIEZOELECTRICITY. A crystal such as quartz, tourmaline, or Rochelle salts has the property known as *piezoelectricity.* Piezoelectricity is the generation of a voltage when the crystal is placed under mechanical strain such as compression or expansion. The reverse of this also is true, since a crystal will expand or compress when a voltage is placed across it. For example, when a Rochelle salts crystal is used in a phonograph pick-up, the slight variation in the record grooves causes the crystal to vibrate and generate a small amount of voltage. This voltage is then fed to an audio amplifier, and reproduced through the speaker. When a voltage is applied to a quartz crystal in a transmitter, it vibrates at a frequency determined by the thickness of the crystal and the manner in which it is cut.

b. QUARTZ CRYSTAL PROPERTIES. Quartz crystals are not affected by light shocks or moisture and are very hard. They have low internal friction when vibrating, and since there is very little damping they make excellent oscillators. The natural frequency of vibration depends on the thickness of the crystal which is placed between two metal plates and allowed some freedom to vibrate.

c. CRYSTAL CIRCUIT. A of figure 4 shows a typical crystal oscillator circuit with feedback accomplished through the grid-to-plate capacitance of the tube. Electrically, the crystal is the equivalent of an L-C tuned circuit in a tuned-plate tuned-grid oscillator (B of fig. 4).

d. OPERATION. When the switch is turned on, current starts to flow in the plate circuit of the tube. A small amount of voltage from the output is fed back to the crystal in the grid circuit through the interelectrode capacity of the tube, C_{gp}, and causes it to compress or expand. The crystal then springs back to its normal position and in so doing generates a voltage. This voltage controls the flow of current through the tube and acts to reinforce the oscillations in the plate circuit. The tuned-plate circuit continues to feed a voltage to the grid, and the action continues. The tuned-plate circuit and the crystal each acts to keep the oscillations of the other going.

e. ADVANTAGES AND DISADVANTAGES OF CRYSTAL OSCILLATOR. Crystal oscillators are stable in operation, since their frequency deviation is small. They also can be used to supply harmonics for frequency-multiplying circuits. However, the frequency of a crystal oscillator

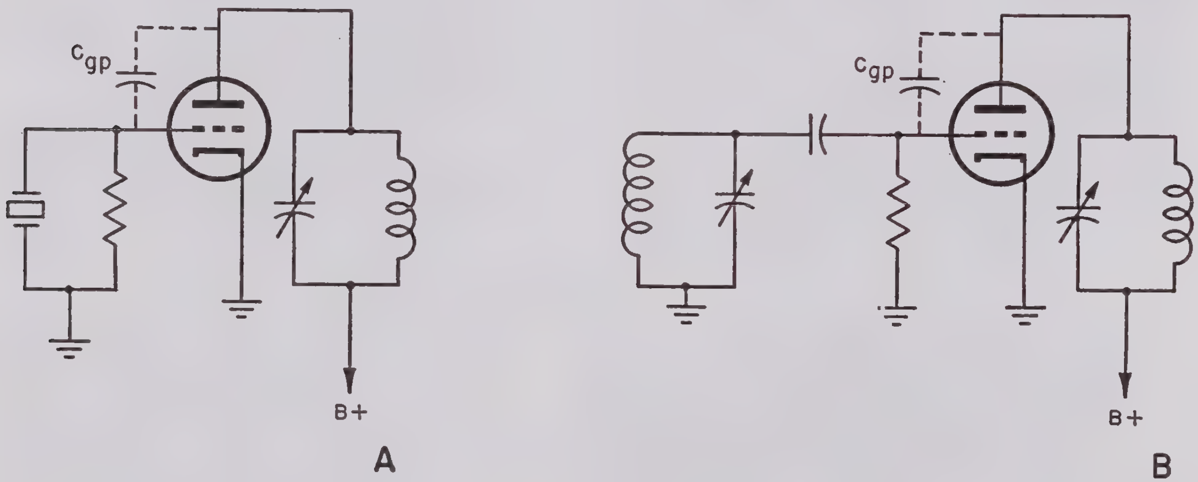


Figure 4 . Crystal oscillator circuit and electrical equivalent.

is not variable and, to change frequency, a different crystal must be used. When their rated current is exceeded, the amplitude of vibration may become so great that the crystal will crack.

5. Audio Oscillator

a. SINE-WAVE AUDIO OSCILLATOR. The range of hearing is, approximately, from 16 to 16,000 cps, depending on the individual. Sine-wave audio oscillators generate signals above and below this range and are useful in checking audio-amplifier circuits for operation, voltage, gain, and frequency response.

b. CHECKING A-F AMPLIFIER FREQUENCY RESPONSE. Theoretically, audio-frequency amplifiers should amplify the entire audio-frequency range equally. In most audio amplifiers, however, the low and the high frequencies are not amplified as much as the middle frequencies; in military application, this response sometimes is deliberately limited. To test an audio amplifier for frequency responses, a sine-wave audio oscillation can be used. A constant value of signal is applied to the input of the amplifier and the output of several frequencies throughout the entire range is measured at the amplifier output with an a-c voltmeter or an oscilloscope (B of fig. 5). The result of these measurements can be shown in a chart called a *frequency-response curve.*

c. SQUARE-WAVE GENERATORS.

(1) The square-wave generator is used for a quick check of the frequency response of an audio-frequency or video-frequency amplifier. Since square waves are rich in harmonics, a poor

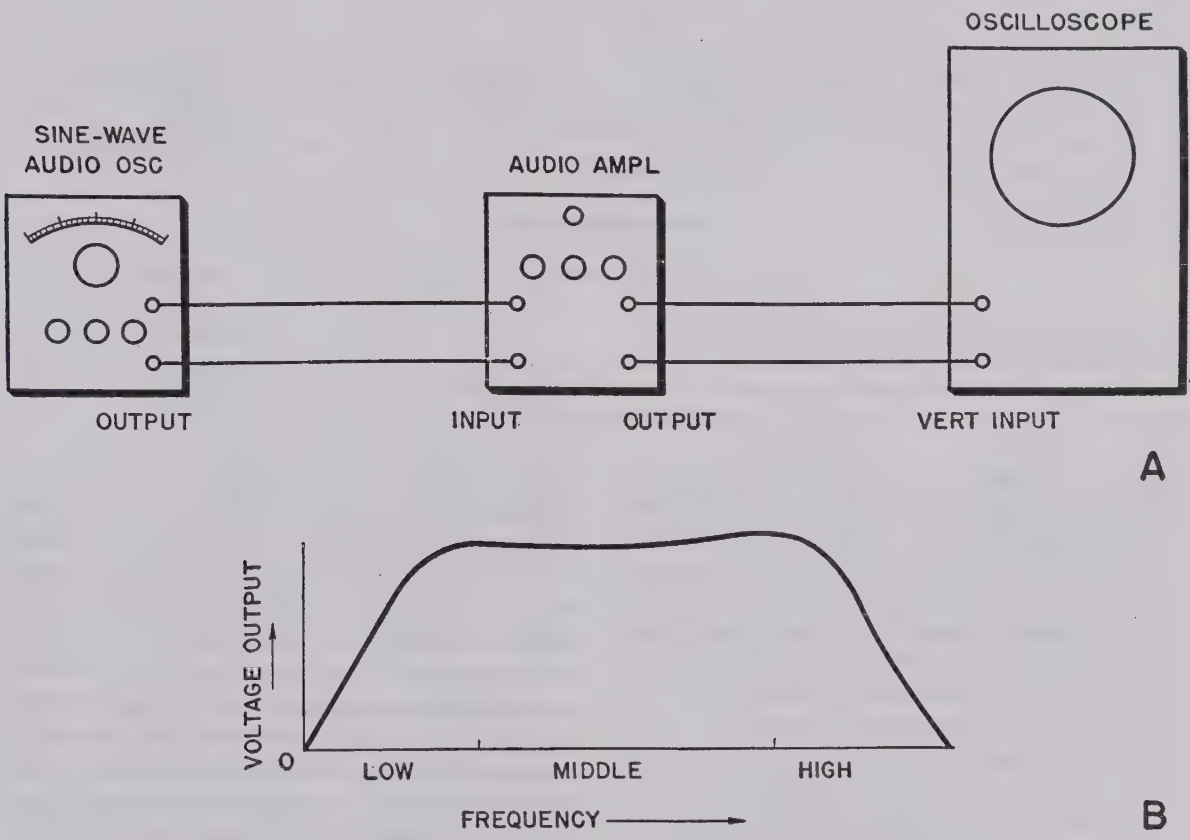


Figure 5. A. Using sine-wave audio oscillator and oscilliscope to check frequency response of audio amplifier. B. Amplitude of output plotted against audio frequency.

frequency response will distort the square wave, and the amount of distortion can be seen easily on the scope. One method of producing square waves is to generate sine waves in an oscillator in the usual way. The sine waves then are fed to an amplifier which is driven to plate saturation on the positive half-cycle of the input signal and to cut-off on the negative half-cycle. This causes the peaks of the sine wave to be cut off at the top and bottom, and produces a square wave (fig. **6**).

r-f signal; modulating circuits to produce the type of modulation desired; an attenuating circuit to provide any desired variation in the output; and a meter circuit to measure and indicate the signal output. These generators must be well shielded to prevent stray signal pick-up by the receiver. The signal voltage is fed to the receiver through the shielded output leads of the generator to prevent misleading results that can be obtained when making receiver sensitivity tests and similar performance tests.

b. A-M GENERATORS. Figure 8 shows a block diagram of an a-m generator. There are two oscillators, one for generating rf at the re-

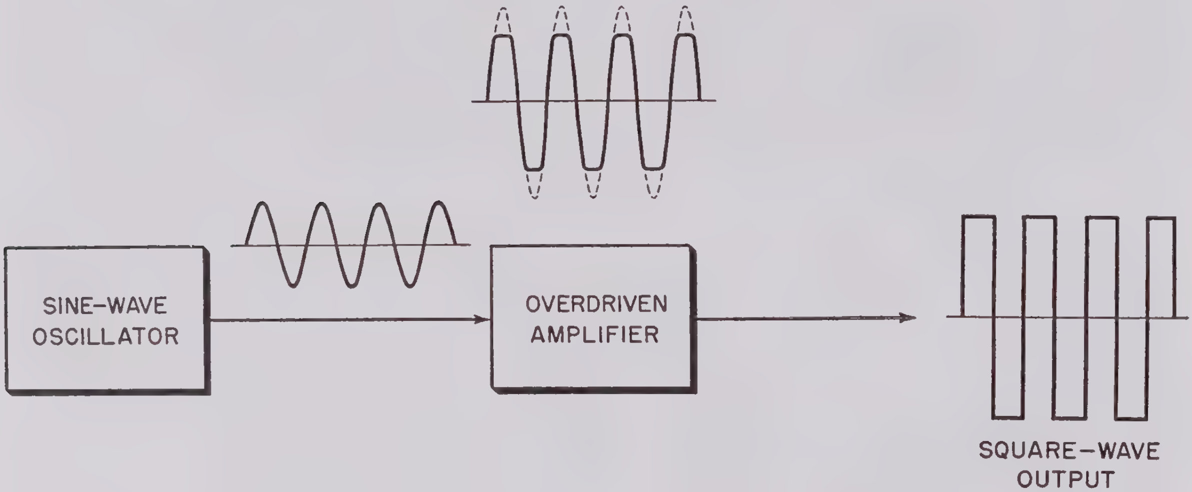


Figure **6**. *Square-wave production from sine waves.*

(2) To check the frequency response of an amplifier, the square waves are fed to the amplifier input and an oscilloscope is attached to the amplifier output. The method of connection and the various output waveshapes that can result for different frequency responses are shown in figure **7**.

6. R-F Signal Generator

a. COMPONENT CIRCUITS IN R-F GENERATORS. An r-f generator consists of a basic oscillator circuit that generates an r-f signal whose frequency is variable over the required range; amplifier circuits to build up the amplitude of the

quired frequency, and the other to generate an audio voltage. The audio voltage may be a set frequency (generally 400 cycles) or variable over the entire audio range. An amplitude-modulated signal is produced by combining the a-f and r-f signals in the mixer. This signal is then amplified in the amplifier section and fed to the attenuator. Generally, the a-m generator gives the technician a choice of three outputs: unmodulated rf (continuous wave), amplitude-modulated rf (modulated continuous wave), or a 400-cycle audio note. A-m generators can be used with both a-m and f-m receivers for alinement, receiver performance tests, trouble shooting, signal substitution, and signal tracing.

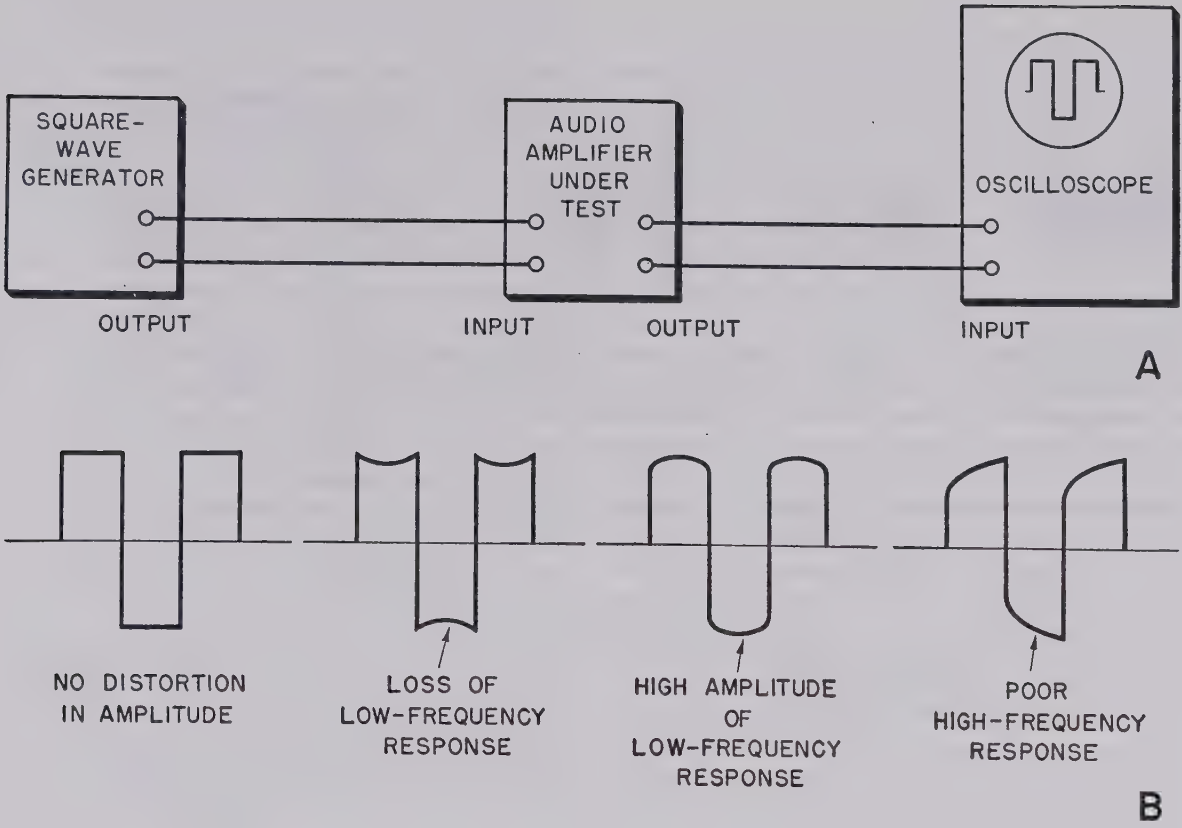


Figure 7. Square-wave testing amplifiers.

c. F-M GENERATORS.

(1) F-m generators provide an r-f signal that varies in frequency. When an audio signal is mixed with a radio frequency whose amplitude is constant, the rf changes in frequency at a rate determined by the instantaneous amplitude of the audio signal. On one alternation of the audio signal, the r-f frequency is higher than the resting, or original, frequency; on the other alternation of the audio signal, the radio frequency is lower than the resting frequency. The rf is no longer a steady frequency, but a shifting one, and the amount of frequency shift from the center frequency is called the *deviation.* The amount of deviation depends on the amplitude of the audio signal and the number of times per second it takes place depends on the frequency of the audio signal. The amount of deviation may vary from a few kilocycles to 10 megacycles or more.

(2) The basic unit of the f-m generator is an oscillator that generates a continuous rf at a given frequency. To obtain an f-m signal, there must be an audio signal that will cause the frequency of the rf to vary with it. One method of producing an f-m signal is to take a 60-cps audio signal from the filament winding of a power transformer and feed it through a potentiometer to the voice coil of a small permanent-magnet loudspeaker. By varying the resistance of the potentiometer which is in series with the

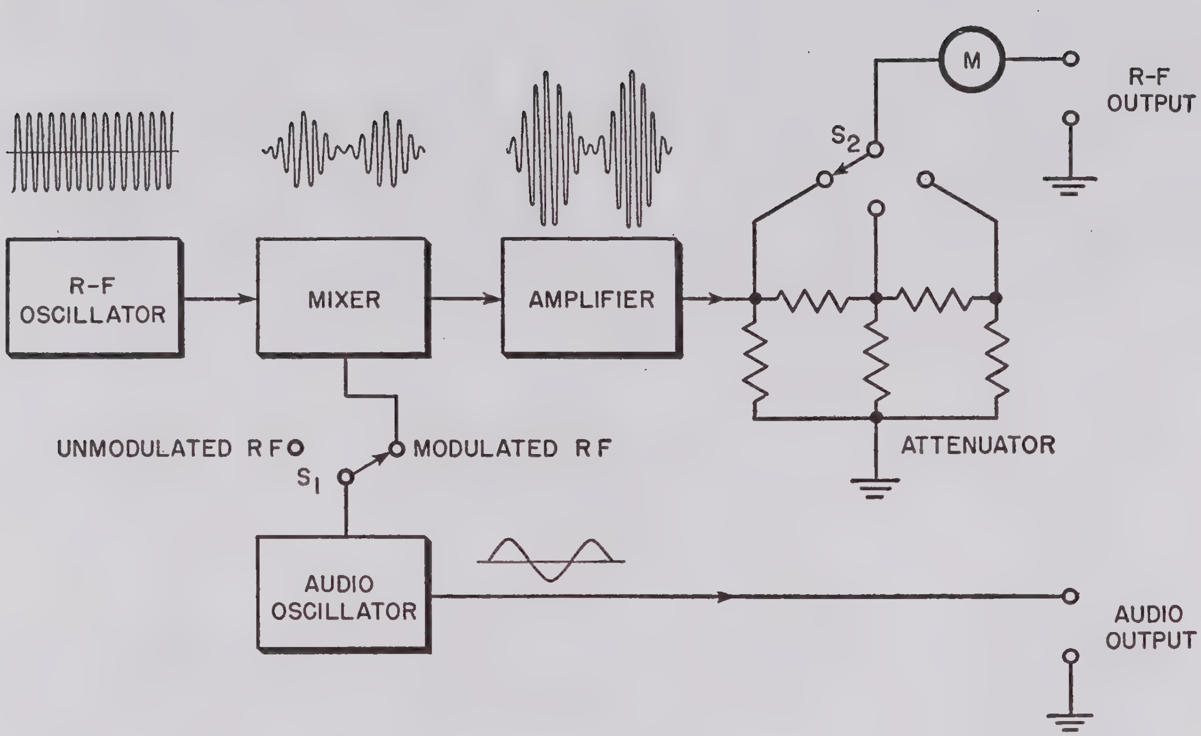


Figure 8 . Block diagram of simplified a-m generator.

voice coil, the amount of vibration of the speaker cone can be varied.

(3) If a copper disk is attached securely to the speaker cone and mounted close to the coil of the r-f oscillator circuit, when the disk comes closer to the r-f coil, eddy currents are induced in the disk. The lines of force from the disk oppose the lines of force from the r-f coil. Therefore, the effective inductance of the coil will be reduced and the frequency of the tuned circuit becomes higher. When the disk moves away from the r-f coil on the other alternation of the audio cycle, the frequency change is in the opposite direction. The amount of frequency change can be regulated by adjusting the amount of vibration of the speaker cone. This is done by controlling the amplitude of the 60-cps input to the voice coil.

(4) To sum up, a 60-cps audio signal causes the f-m signal to vary on either side of the resting frequency 60 times per second. Also, the higher the amplitude of the audio signal, the greater the frequency deviation of the f-m signal. F-m generators are used for visual alinement of a-m, f-m, and television receivers, and alinement and testing of some types of radar receivers.

d. PULSE-MODULATED GENERATORS.

(1) In a p-m (pulse-modulated) generator, the rf is interrupted or pulsed at an audio-frequency rate. Controls are provided to vary the *pulse width* (duration of each pulse of rf) and the *repetition rate* (number of pulses per second).

(2) To pulse-modulate the r-f signal, a constant rf is generated in a conventional oscillator circuit. A square wave is generated in another circuit and both the rf and the square wave are fed to different grids of an amplifier tube. For example, the r-f signal is fed to the control grid, and the square wave is fed to the suppressor grid. The r-f

signal on the control grid is a continuous wave. The square-wave signal on the suppressor grid is first positive, and then negative. When the square-wave signal on the suppressor is negative, plate current is cut off and all of the tube current flows to the screen grid. When the suppressor grid has a positive square wave applied to it, current flows from cathode to plate.

(3) The plate current is controlled by the r-f signal on the control grid. Therefore, the current arriving at the plate is an r-f signal that lasts for the period of the positive square wave. The pulses then can be fed to one or more amplifier stages. The duration of the pulses and the number of pulses per second are varied by controls in the square-wave circuit.

(4) Pulse-modulated generators are useful in checking the performance of many kinds of radar receivers, since these sets usually send and receive signals in pulse form.

7. Alinement of A-M and F-M Receivers

a. REASONS FOR ALINEMENT. One of the major uses of the signal generator is receiver *alinement*. Alinement is the process of adjusting the tuned circuits of a radio receiver to the correct operating frequencies. The need for alinement can arise for one or more of the following reasons: aging of tubes; replacement of defective parts or tubes; change in the placement of wires; vibration; climatic conditions. *Alinement should not be attempted until other simple possibilities of trouble have been ruled out.*

b. SUPERHETERODYNE OPERATION. The superheterodyne receiver generally is used for a-m and f-m reception. A brief review of the operation of a typical a-m superheterodyne receiver (fig. 9) is offered to clarify the requirements for alinement. Incoming signals strike the antenna and set up magnetic fields around the r-f amplifier TC_1. The tuned circuit in TC_1 selects the desired r-f signal and prevents other signals from reaching the next stage. The selected signal then is amplified in the r-f stage and proceeds to the mixer stage. TC_2 in the mixer stage provides greater selectivity, allows the desired r-f signal to pass, and keeps out any other signals that may have been passed by the r-f stage. Tuned circuits TC_1 and TC_2, therefore, always are tuned to the frequency of the incoming signal. The tuned circuit of the oscillator stage, TC_3, is tuned to a definite frequency above or below the incoming frequency, and is fed to the mixer where it mixes with the incoming signal to produce new frequencies. These include the desired intermediate or difference frequency. For example, if the incoming signal is 1,000 kc and the oscillator frequency is 1,456 kc, the two signals will mix and produce an intermediate frequency of 456 kc (1,456 kc minus 1,000 kc = 456 kc). No matter what the frequency of the r-f circuits, the oscillator circuit is tuned so that it will produce the same intermediate frequency. Many other frequencies appear at the plate of the mixer stage, but only the intermediate frequency passes through to the next stage because TC_4 and TC_5, in the plate circuit of the mixer and grid circuit of the i-f amplifier, are tuned to the intermediate frequency. Tuned circuits TC_6 and TC_7 in the plate circuit of the i-f amplifier and input circuit to the detector are also tuned to this frequency. At the detector, the audio signal is separated from the intermediate frequency and passed through an audio-amplification stage to the speaker voice coil, which changes the electrical signals to sound.

c. ALINEMENT POINTS IN A-M RECEIVERS. The purpose of alinement in an a-m superheterodyn receiver is to tune the r-f circuits to the desired r-f range of the receiver, tune the local oscillator so that it tracks with the r-f circuits through the band, and tune the i-f circuits to the fixed intermediate frequency. TC_1 and TC_2 always must be tuned to the same frequency, and TC_3 must be tuned to a frequency different from TC_1 and TC_2 by the exact amount of the intermediate frequency. The i-f transformers, TC_4, TC_5, TC_6, and TC_7, are tuned to the desired frequency.

d. F-M RECEIVER ALINEMENT. In an f-m superheterodyne receiver, the i-f, r-f, and oscillator sections are alined in the same manner as the a-m receiver. The f-m detector, which is usually more complex than the a-m detector, requires an additional step in alinement. Spe-

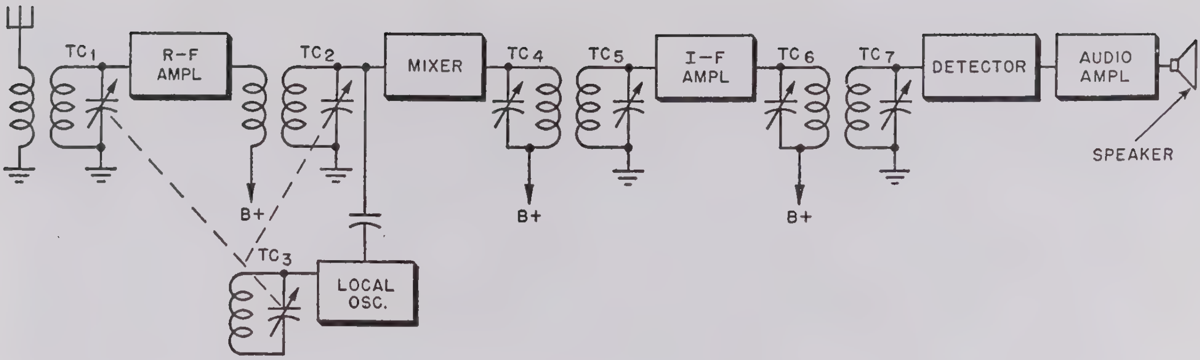


Figure 9. *Outline of typical superheterodyne receiver showing tuned circuits.*

cific alinement procedure for either f-m or a-m receivers is given in the technical manuals furnished with the equipment. The instructions should be followed closely.

e. Dummy Antenna (fig. 10). The dummy antenna matches the impedance of the signal generator to the impedance of the receiver and serves as a convenient means of injecting the signal. It is placed between the hot lead of the signal generator and the receiver antenna terminal and should have the same electrical characteristics as the actual antenna. The dummy antenna to be used usually is specified in the receiver instruction manual.

f. Output Indication. In alinement, the output indicator is read for a maximum value of output. Therefore, the indicator can be connected at places other than across the output. One method is to connect the indicator to the plate of the power output tube. At this point, the audio signal has maximum voltage amplitude and when circuits are badly misalined, the output indicator will provide the most sensitive indication.

g. Types of Output Indicators.

(1) Instruments used as output indicators during alinement show relative values of amplitude. The most popular instruments for this purpose are either the copper-oxide rectifier or vacuum-tube a-c voltmeters, output meters, or oscilloscopes.

(2) An output meter in either type of a-c voltmeter plus a capacitor in series with one lead for the purpose of keeping out d-c and allowing ac to pass.

(3) An output meter is used when an indication is to be taken at a point where both ac and dc are present, such as the plate of the power output stage. Although a-c meters respond to either ac or dc, only the a-c signal coming through the receiver is important for alinement purposes. Therefore, when a meter is used at the power amplifier plate, it should be an output meter rather than an a-c voltmeter. At the receiver output, where only ac is pres-

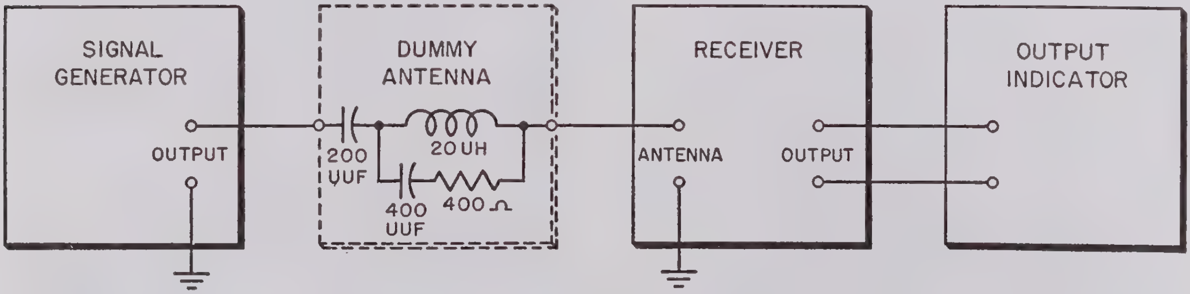


Figure 10. *Dummy-antenna circuit connected between signal generator and receiver.*

ent, either an a-c voltmeter or an output meter can be used.

h. OSCILLOSCOPE.

(1) An oscilloscope gives a visual indication on a crt (cathode-ray tube) of any a-c voltage waveform applied to the vertical input. An oscilloscope panel is shown in figure 11. The name and purpose of each control is indicated in table I. Because there is an internal coupling capacitor, the oscilloscope input leads can be placed at a point where there is only ac, or where there is both ac and dc.

(2) The oscilloscope can be used as an output meter, an a-c voltmeter, or a distortion meter. When it is used as an output indicator, the horizontal gain control can be set at 0. The output of the receiver, then, will show as a vertical line increasing in amplitude as the output increases (fig. 11). The trace is observed for maximum height without attempting exact measurement. The oscilloscope also can measure the exact amplitude of the a-c signal by first feeding a known voltage to the input and observing its exact height. The signal to be measured then is fed to the input and its amplitude is compared with that of the known voltage. The vertical amplitude control of the oscilloscope *is not to be varied* when the unknown signal is fed to the input. The oscilloscope can measure peak voltages, not only of sine waves but also of irregular waveforms that are almost impossible to measure accurately with any other kind of meter.

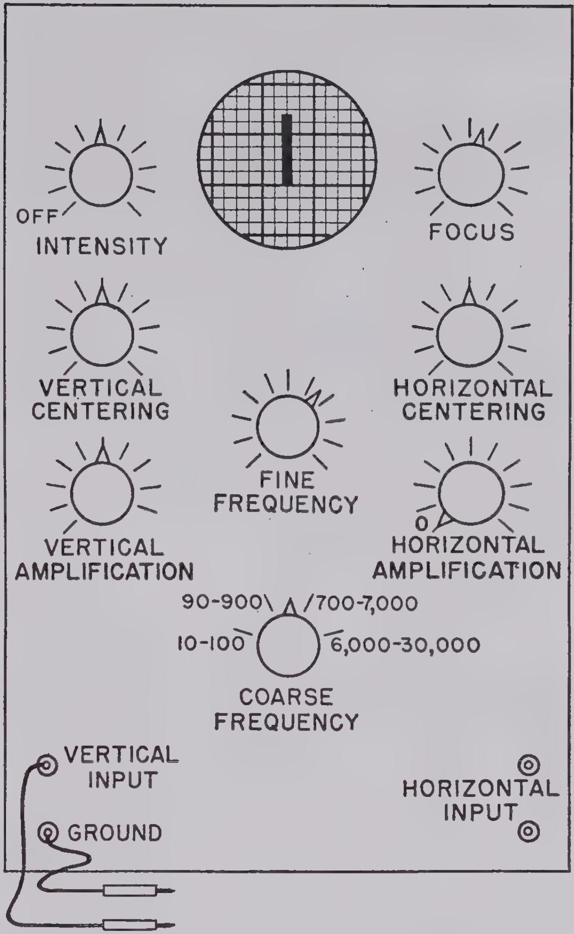


Figure 11 Typical oscilloscope.

Table I. Oscilloscope Controls and Functions

Control, jack, or switch	Function	Position for output indication or waveform observation
On-off switch	Turns power on or off	Intensity control is rotated clockwise to turn power on.
Intensity control	Varies brightness of trace	Adjusted for good visibility.
Focus control	Varies sharpness of trace	Adjusted for clear, sharp trace.
Vertical centering control	Varies vertical position of trace.	Control usually is centered, then readjusted if necessary.
Horizontal centering control	Varies horizontal position of trace.	Control usually is centered, then readjusted if necessary.
Vertical amplifier control	Varies vertical size of waveform.	Control is adjusted to desired vertical size.
Horizontal amplifier control	Varies horizontal size of waveform.	For output indication, control is set at zero so that only a vertical line appears. For waveform observation, control usually is set until horizontal size is just within limits of screen.
Frequency controls	Make observed waveform stand still.	Set at the same frequency as that of the signal being observed.

(3) A third use of the oscilloscope is as a distortion meter. Assume that the output of the receiver is distorted, and some point in the audio section is suspected. A sine wave at an audio frequency can be fed to the input of the audio section. The oscilloscope then can be connected in turn to each of the audio stages to find at which point the distortion is developing.

i. VISUAL ALINEMENT OF A-M AND F-M RECEIVERS. A-m and f-m receivers can be alined visually by using an f-m generator and an oscilloscope. Visual alinement, however, is somewhat more difficult and not necessarily more accurate than the basic alinement method described above, which uses an a-m signal generator and an output indicator.

8. Receiver Servicing

a. USE OF SIGNAL GENERATOR IN SERVICING. There are two general methods of using signal generators for servicing defective receivers—signal substitution and signal tracing. When a receiver develops trouble and the cause of the defect is not immediately apparent, the first step is usually to test the tubes. If this does not clear up the trouble, the standard procedure in trouble shooting is to find the defective stage by either the signal substitution or the signal tracing method.

b. SIGNAL SUBSTITUTION.

(1) In signal substitution the signals from the generators are applied to each stage of the receiver to determine whether the stage can pass the signal. For example, to check the operation of the audio section, an a-f signal is injected at the grid of the audio output stage. If the stage passes the signal it is assumed to be in working order and the generator is moved to the plate of the preceding audio stage, then to the grid, until the entire audio section has been covered. If the signal is passed along and amplified from each point, the a-f stages are operating and the i-f stages should be checked.

(2) A modulated i-f signal is applied to the i-f section, starting with the plate of the last i-f stage. Then work back to the mixer plate, listening for the modulation output at the speaker. If the i-f stages pass the signal, the mixer, oscillator, and r-f stages must be checked.

(3) Apply the modulated r-f signal to the grid of the mixer stage and note whether the signal appears at the receiver output when the set is tuned to the signal frequency. If this stage is operating, work back through the r-f stages to the antenna terminal. When the r-f signal does not appear at the output of the mixer, the oscillator stage should be checked for operation. A simple way to determine oscillator operation is to check the negative voltage on the grid. The minimum usually necessary for operation is —5 volts; however, the amount of negative voltage varies with different receivers and should be checked against the instruction manual. If any stage fails to pass a signal when using signal substitution, the trouble is localized in that stage. The individual parts for that stage should then be checked for defects.

c. SIGNAL TRACING.

(1) The second method for localizing trouble is signal tracing. This method is similar to signal substitution, but the procedure starts at the antenna terminals of the receiver instead of the audio output stage.

(2) In signal tracing, a signal generator supplying a modulated r-f signal of predetermined amplitude is connected to the antenna terminals of the receiver. This signal is then followed or traced through various stages of the receiver by connecting an indicating device first to the input and then to the output of each succeeding stage. The point where the signal disappears indicates the defective stage, and the individual parts within that stage should be checked.

(3) Indicator units used in signal tracing should be suitable for the circuit under test. The audio-amplifier stages require an output meter, speaker, or

oscilloscope as an indicator. Amplifiers operating at radio frequencies require a test instrument that provides an indication at radio frequencies. These can be r-f vtvm's, r-f oscilloscopes, detectors with an audio amplifier, or special signal-tracing equipment.

d. SIGNAL-TRACING CHARTS. In receivers that operate but do not meet sensitivity specifications, the signal-tracing method is often used to measure the relative gain of the signal through each successive stage of the receiver. Receiver instruction manuals usually contain signal-tracing charts which give information on where to apply the input signal, what amplitude the input signal should be, where to connect the indicating device, and the indication that should be obtained if the stage is operating properly. With this information, the trouble can be localized quickly to a specific stage. Then the individual parts within the stage can be checked for defects. The signal substitution method also can be used to localize trouble in weak receivers if calibrated audio and r-f signal generators are used to inject a signal of the frequency and amplitude specified in the signal-tracing chart.

9. Summary

a. A signal generator produces a-c voltages at various frequencies. There are audio-frequency generators and radio-frequency generators.

b. A-f generators have either a sine-wave output or a square-wave output.

c. R-f generators can have an a-m, f-m, or a pulse-modulated output.

d. Signal generators are used for receiver alinement, receiver performance tests, and receiver servicing.

e. The basic stage in all signal generators is the oscillator stage.

f. An r-f oscillator is a vacuum-tube amplifier circuit consisting usually of a tuned circuit, L and C, with proper feedback to sustain oscillations.

g. A crystal oscillator uses a quartz crystal instead of an L-C circuit in the grid of the oscillator stage.

h. A crystal oscillator is the electrical equivalent of a tuned-plate tuned-grid oscillator and uses capacitive feedback from plate to grid to sustain oscillation.

i. Crystals operate on the principle of piezoelectricity, the generation of voltage by the compression and expansion of the crystal under mechanical strain. Conversely, the crystal expands and compresses when a voltage is placed across it.

j. Sine-wave audio oscillators are useful in checking the frequency response of audio amplifiers.

k. Square-wave generators can be used to check amplifier frequency response by observing the output waveshape on an oscilloscope.

l. R-f signal generators usually consist of a basic oscillator circuit, amplifier circuits, modulating circuits, attenuating circuit, and meter circuit.

m. Alinement is the adjustment of the tuned circuits of a receiver to their correct frequencies.

n. One method of alining both a-m and f-m receivers is to use an a-m signal generator and an output indicator.

o. Output indicators used for a-m receivers are a-c voltmeters, output meters, and oscilloscopes.

p. When f-m receivers are alined with an a-m generator, the output indicator used generally is a vtvm.

q. When a signal generator is used to inject a signal into a receiver at the antenna terminals, a dummy antenna is put in series with the hot generator lead.

r. To service receivers, a signal generator can be used for signal substitution or signal tracing.

s. Signal substitution is the process of injecting a signal of the correct frequency into each stage. It is customary to start at the last audio stage and work back to the antenna.

t. Signal tracing starts at the antenna terminals with a given value of input signal from the generator. Then an indicating device is used at each stage, working back to the speaker, to find where the signal is lost or not amplified sufficiently.

10. Review Questions

a. What is a signal generator?

b. Classify a-f generators by type of output.

c. Classify r-f generators by type of output.

d. What are the main uses for signal generators?

e. Define damping, tuned circuit, resonant circuit.

f. A tuned circuit is connected across a battery for an instant. Describe what occurs.

g. What factors govern the frequency of oscillation and damping?

h. List the factors necessary for sustained oscillation in any oscillator.

i. Define piezoelectricity.

j. What are the advantages and disadvantages of crystal oscillators?

k. How are square-wave generators used to check amplifier frequency response?

l. List the basic circuits in r-f generators.

m. Why is shielding important in r-f signal generators?

n. Draw a block diagram of an a-m generator.

o. Define pulse modulation, pulse width, pulse repetition rate.

p. List five conditions which can make receiver alinement necessary.

q. Why are dummy antennas used?

r. List three output indicators for use in alining an a-m receiver and where each can be applied.

s. Describe signal substitution in receiver servicing.

t. Describe signal tracing in receiver servicing.

II. FREQUENCY MEASUREMENT

1. Introduction

Indirect methods of measuring frequency by means of signal generators, oscilloscopes, and output meters have been discussed in previous chapters. Frequency or wavelength, however, may be determined also by frequency-measuring devices, known as *wavemeters* or *beat frequency meters*. These meters indicate the fundamental or harmonic frequencies of oscillators or harmonic generators on a calibrated dial. The wavemeter is calibrated in terms of wavelength, and contains a variable tuned circuit whose resonant frequency is determined by the unknown frequency. The beat or heterodyne frequency meter uses an oscillator to generate signals of known frequencies and compares these with the unknown frequency.

2. Wavemeters

There are two basic wavemeters, both of which absorb part of the output power of the device whose frequency is to be measured. The *reaction wavemeter* absorbs very little power, and an ammeter, located in the circuit of the device whose frequency is to be measured, usually serves as an indicator. Since the power absorbed is not sufficient to load the equipment being measured to any great extent, it can be used to measure the frequency of low-power equipment. The *absorption wavemeter* is more accurate than the reaction wavemeter and absorbs slightly more power from the equipment whose frequency is being measured. It generally is used on high-power equipment only, since it tends to load the equipment. An ammeter, a lamp, or an earphone is used to indicate the unknown frequency.

a. REACTION WAVEMETER.

(1) The basic circuit of a reaction wavemeter containing a coil, L, and a variable capacitor, C, is shown in figure 1. The external coil, L, is loosely coupled to the output coil of the device whose frequency is to be measured. The capacitor, C, then is tuned until the resonant frequency of the wavemeter is equal to the frequency of the device under test. At this point the ammeter indicates resonance which can be either maximum or minimum, depending on where the ammeter is located in the device under test. The capacitor is operated by an accurately calibrated vernier dial, with the graduations in terms of some arbitrary unit. The frequency or wavelength is found by means of a calibration curve or chart which relates the dial setting to either frequency or wavelength.

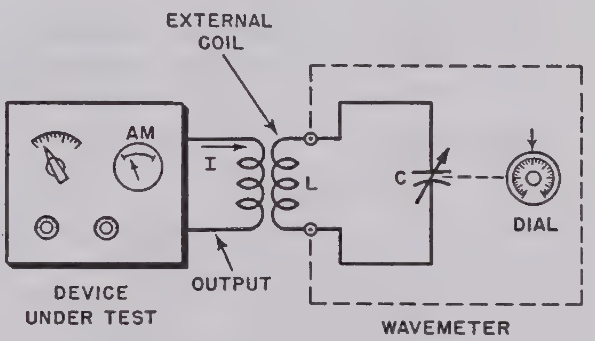


Figure 1. Basic circuit of reaction wavemeter.

(2) When the wavemeter is moved into the r-f field of the device under test, the coupling produces a change in the current, and increases the load on the device. When the wavemeter is tuned to resonance, this load becomes maximum, and the indicating ammeter reads a minimum or maximum, de-

pending on its location. To prevent loading of the equipment being measured, the wavemeter is moved away until the least possible variation of the tuning capacitor causes a maximum deflection on the meter (curve A, fig. **2**).

(3) A plot of output current versus wavemeter frequency for various degrees of coupling is shown in figure **2** . When the wavemeter is resonant, the load on the device is a maximum and the current is a minimum. The dips in the curves indicate a dip in the reading of the ammeter. Curve A indicates loose coupling (the wavemeter has been moved away from the equipment being measured). As the coupling is increased, the dip in primary current becomes greater. Curve B represents tight coupling, curve C critical coupling, and curve D overcoupling. *For accurate frequency measurements, the coupling is decreased until there is a very small dip in the current meter.* Loose coupling is ideal for accurate frequency measurements, since its dip at resonance is very sharp.

b. ABSORPTION WAVEMETER.

(1) Although the absorption wavemeter is similar to the reaction wavemeter, it contains also a resonant-frequency indicating device. Figure **3** shows an absorption wavemeter circuit using a lamp to indicate resonance. The functions of tuning capacitor C_1 and external coil L are identical with those explained in the discussion of the reaction wavemeter. The lamp is at maximum brilliance when the wavemeter is at the resonant frequency of the device under test. The amount of brilliance that results is dependent on the voltage appearing across fixed capacitor C_2. The capacitive value of C_2 is much larger than that of C_1, and, since its reactance is negligible at the resonant frequency, C_1 and L determine the resonant frequency of the wavemeter.

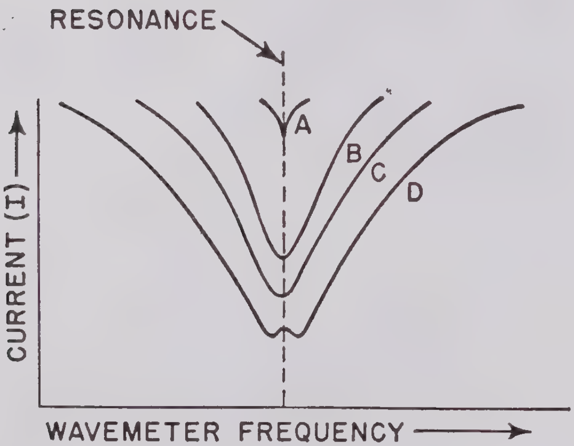


Figure **2**. *Coupling effects on output current using reaction wavemeter.*

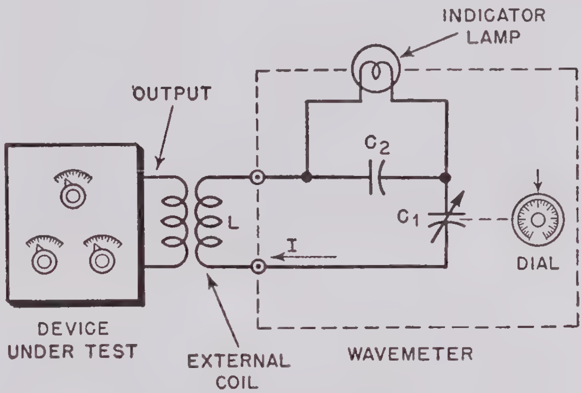


Figure **3**. *Basic circuit of absorption wavemeter.*

(2) When the wavemeter circuit is tuned to the same frequency as the unknown frequency, a maximum circulatory current flows in the wavemeter circuit. Since this circulatory current occurs at resonance and current is maximum at resonance, voltage drops appear across L, C_1, and C_2 and the voltage drop across C_2 causes the lamp to glow. As C_1 is tuned to either side of resonance, the circulatory current becomes less and the lamp grows dimmer.

(3) In figure **4** , the circulatory current is plotted against the wavemeter frequency for various degrees of coupling. For accurate frequency measurements, the external coil of the wavemeter is

loosely coupled to the device under test. This accuracy is indicated by the sharpness of curve C at resonance. Although overcoupling, as shown in curve A, produces a greater circulatory current and lamp brilliance, it results in inaccurate frequency measurements. Overcoupling results in a double-humped curve where a maximum circulatory current is obtained on either side of resonance.

(4) In A of figure 5, the headphones of the absorption wavemeter are coupled to the wavemeter circuit by means of small pick-up coils and are used as the indicating device. Resonance is obtained when a *click* is heard in the headphones as C_1 is tuned slightly above and slightly below resonance. The crystal rectifier is used to obtain the direct current necessary to operate the headphones.

(5) In B, a d-c meter movement replaces the headphones, a diode rectifier replaces the crystal, and the circuit operates as a simple vacuum-tube voltmeter. The diode is a filament-type tube operated by means of a small self-contained battery. Resistor R_1 is used to adjust the filament voltage to its proper value. Capacitors C_2 and C_3 bypass the r-f circulatory current around the ammeter and battery. The ammeter reads in direct proportion to the potential difference existing across tuning capacitor C_1. This potential

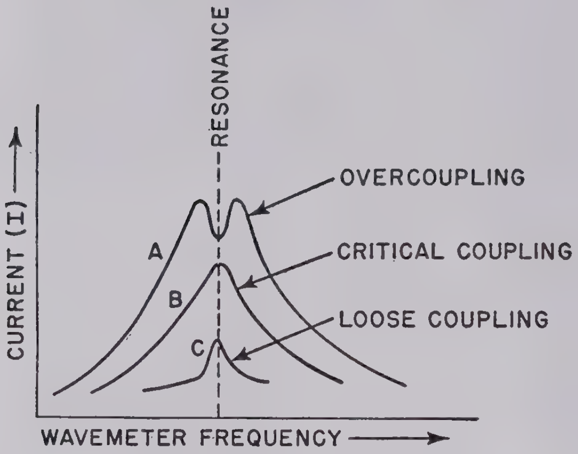


Figure 4. Coupling effects on circulatory current in absorption wavemeter.

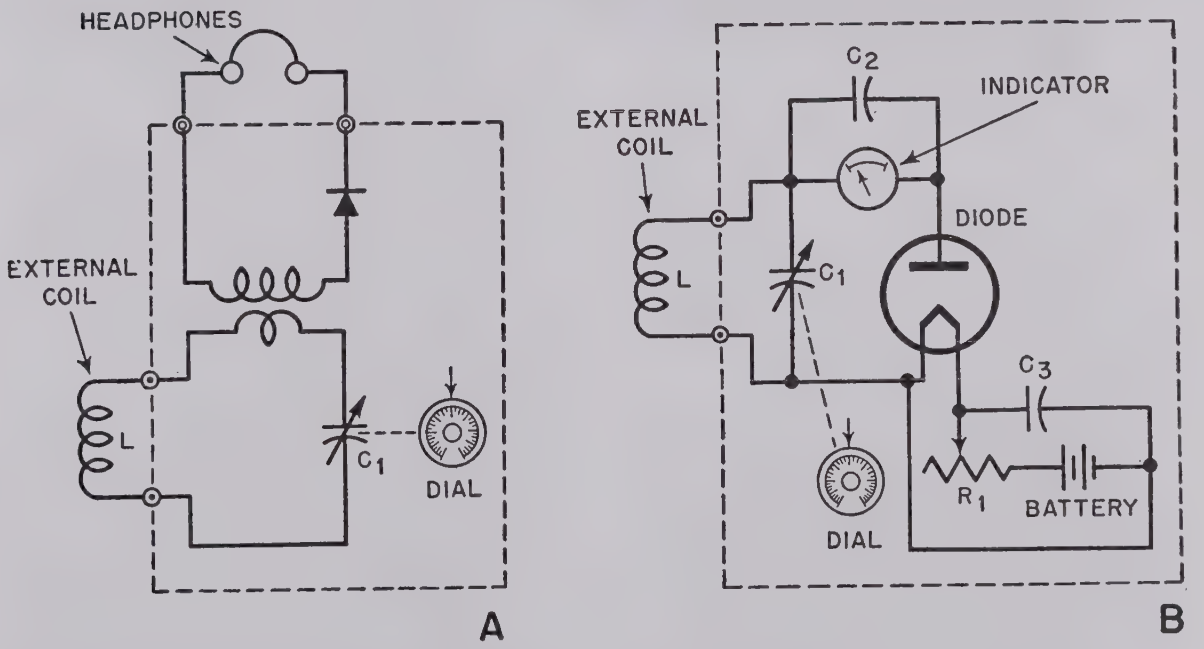


Figure 5. Circuit variations of absorption wavemeter.

difference results from the circulatory current in the wavemeter circuit and, at resonance, the ammeter reads maximum.

c. DETERMINING UNKNOWN FREQUENCY.

(1) In the reaction wavemeter, the frequency to be measured is determined in the following manner: The external coil of the wavemeter is moved into the r-f field of the device whose frequency is to be measured. The knob on the dial setting then is slowly rotated through its frequency range until some reaction is noted on the *indicating meter in the device under test.* The wavemeter is moved slowly away from the oscillator until the deflection on the indicating meter is barely perceptible. The dial setting knob now is adjusted for a maximum deflection on the meter.

(2) In the absorption wavemeter, the frequency to be measured is determined in a similar manner. A lamp is used as an indicator, and the wavemeter is brought near the device under test. The dial setting knob is turned slowly through its range until the indicator lamp just begins to glow. The knob is not turned for maximum lamp brilliance, which might cause it to burn out. The wavemeter is moved slowly away from the oscillator until the lamp glows more dimly or goes out. It then is tuned for maximum lamp brilliance. For accuracy, the wavemeter should be taken as far from the device as possible, where maximum brilliance is a faint glow.

(3) Wavemeters usually contain several external coils of the plug-in variety. Each coil represents a specific frequency range, and if the *approximate* frequency to be measured is known, the selection of the proper coil is simplified. Where the approximate frequency is unknown, each coil must be tried separately to obtain resonant indications. The tuning capacitor is of the air type and the frequency range it covers determines the number of plug-in coils that are needed. A *frequency standard,* from which a fixed known frequency signal can be obtained, is used to calibrate the wavemeter.

(4) Many wavemeters use a micrometer-type tuning dial. The micrometer consists of a thimble with a vernier scale which is rotated about a barrel with a coarse scale. A typical micrometer dial (A of fig. **6**) is read in the following manner: The barrel has major divisions marked on it which represent tenths of an inch or any desired unit that may be represented by tenths of an inch. Each of the four minor divisions between the major divisions represents .025 inch. The thimble is divided into 25 parts around its circumference, and one full rotation moves the thimble one minor division on the barrel or .025 inch. Since the thimble is divided into 25 parts, one division is equal to .025/25 or .001 inch. Consequently, the reading of the micrometer setting in A of figure 91 is .1 plus (.025 times 3) plus .009 = .184 inch. The frequency which represents a reading of .184 inch then is obtained from a calibration chart, shown in B, and is found to be 2,655 mc. The calibration chart, which represents a frequency range from 2,400 to 3,400 mc for micrometer readings from .0557 to .46, is on a metal plate screwed to the back of the wavemeter case.

3. Heterodyne Frequency Meter

a. PRINCIPAL OF OPERATION.

(1) When greater stability and accuracy are desired in direct frequency measurements, the *heterodyne,* or *beat,* frequency meter is used. The basic heterodyne meter (fig. **7**) consists of a frequency-calibrated oscillator which beats, or heterodynes, against the frequency to be measured. The pick-up antenna is coupled loosely to the device under test. The calibrated oscil-

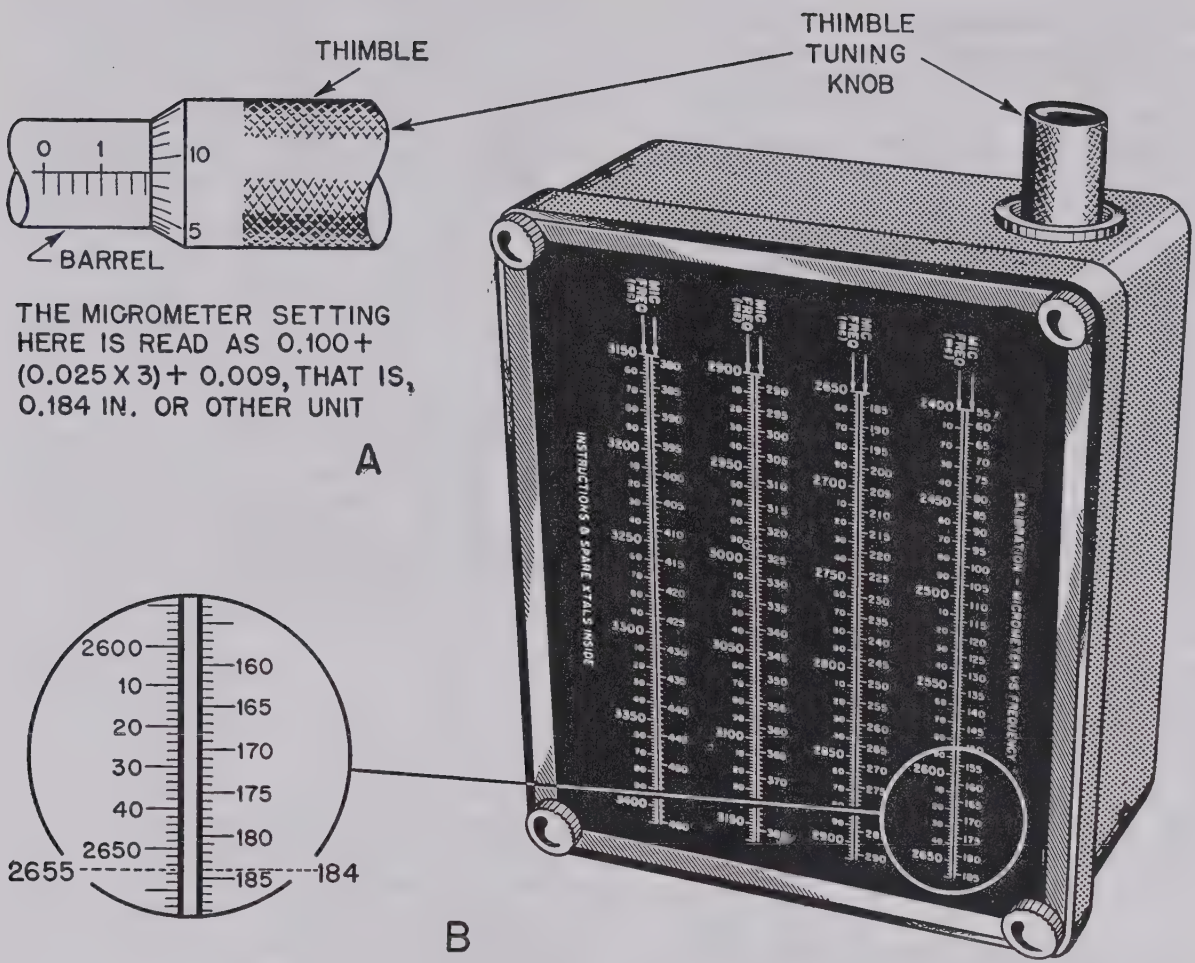


Figure **6**. *How to read a micrometer.*

lator then is tuned so that the difference in frequency between the oscillator and the unknown frequency is in the a-f range. This difference in frequency is known as the *difference* or *beat* frequency and when it is detected and amplified it can be heard in the headphones. If the dial setting of the calibrated oscillator is tuned to the same frequency as the device under test, the difference frequency is zero, or *zero-beat frequency,* and no audible sound is heard in the headphones. When zero-beat frequency is obtained, the position of the pointer on the dial setting represents the unknown frequency.

(2) Figure **8** shows a curve of the beat frequency plotted against the audible range of frequencies. When the difference frequency between the two signals is above the audible range, no sound is heard and the shaded area on the graph indicates the frequencies above audibility. As the two frequencies are brought closer to each other (A on the curve) a high-pitched note is heard in the headphones. This tone gradually decreases in frequency to a point, B, where it is replaced by a

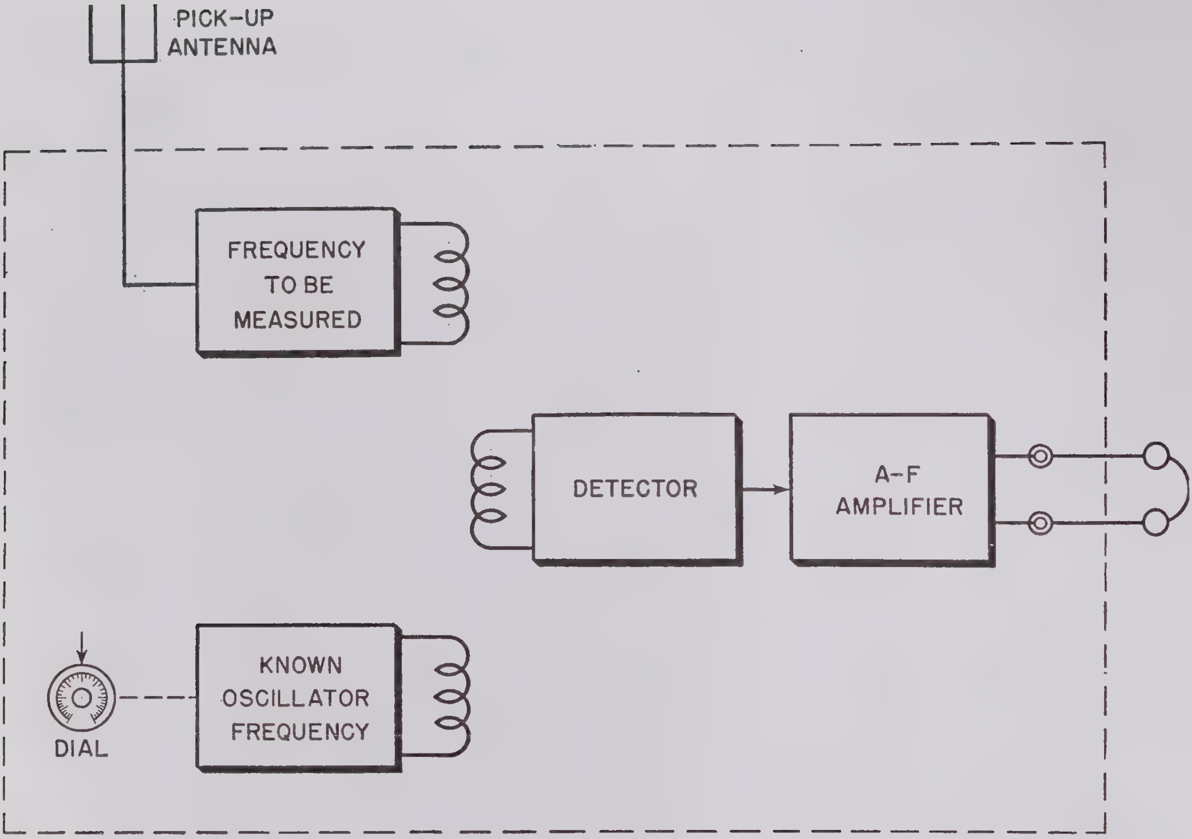


Figure 7. *Block diagram of basic heterodyne frequency meter.*

series of rapid clicks and the difference frequency is then only a few cycles per second. At C, the clicks have stopped completely, the two original frequencies are equal to one another, and this is the exact point of *zero-beat*. Clicks are heard at rather infrequent intervals at point C, since it is difficult to maintain a condition of absolute silence in the headphones over a prolonged interval of time because of a certain amount of circuit instability. As the standard oscillator frequency is varied beyond the zero-beat point, the number of clicks increases to point D. A low-pitched tone again is heard at this point, and varying the frequency in the same direction causes a gradual increase in frequency until point E is reached, where the beat note is again inaudible.

b. CALIBRATION.

(1) Most heterodyne frequency meters contain a stable crystal oscillator which is used for calibrating the frequency of the variable oscillator. The crystal oscillator produces a number of harmonics permitting calibration of the meter at various frequencies. These points of calibration are called *crystal check points* and the frequencies at which they occur are given in a *calibration book* which is used to determine the frequency of the dial setting.

(2) Figure 9 shows a typical arrangement for calibrating a variable-frequency oscillator. Assume that the calibration book shows a crystal check point at a frequency of 3,000 kc. The dial setting of the variable-frequency

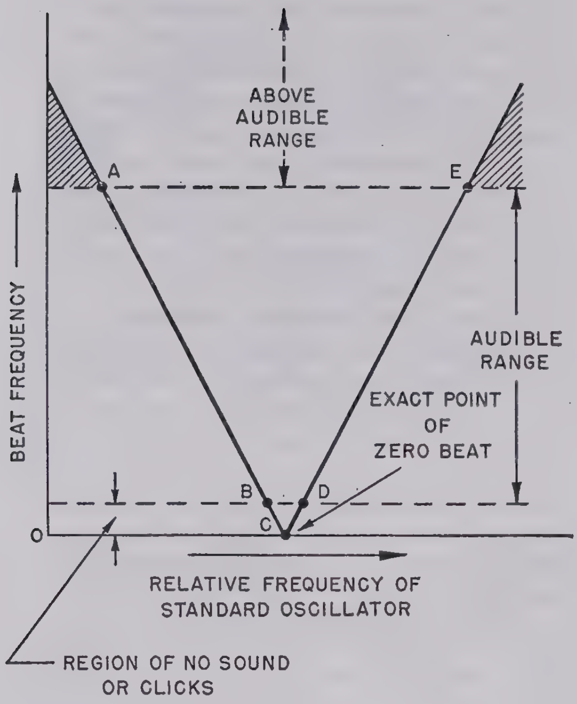


Figure 8. *Beat-frequency chart.*

oscillator is adjusted to represent a frequency of 3,000 kc. If the second harmonic of the 1,500-kc crystal oscillator (3,000 kc) zero-beats against the 3,000-kc output of the variable-frequency oscillator, the output frequency is zero. There is no sound in the headphones, the variable-frequency oscillator already is calibrated, and no compensating adjustment is necessary.

(3) However, if the output of the variable-frequency oscillator is some other frequency than 3,000 kc when the dial is set to 3,000 kc, the variable-frequency oscillator must be calibrated. If it is set at 3,000 kc and the actual frequency is 2999.7 or 3.000.3 kc, the output of the detector then will produce a beat frequency of .3 kc, or 300 cycles, that can be heard in the headphones. The corrector control, usually a small variable capacitor, then is adjusted until the frequency of the variable-frequency oscillator changes to 3,000 kc. When this is done, no audible tone is heard in the headphones and the variable-frequency oscillator has been calibrated. This procedure can be used for all crystal check points listed in the calibration book. *Before* making a correction in the calibration, the frequency meter should be turned on and allowed to warm up for 15 to 20 minutes to permit the operating temperature within the meter to become stable.

BASIC PRACTICAL CIRCUIT.

(1) A basic circuit of the heterodyne frequency meter is shown in figure 10.

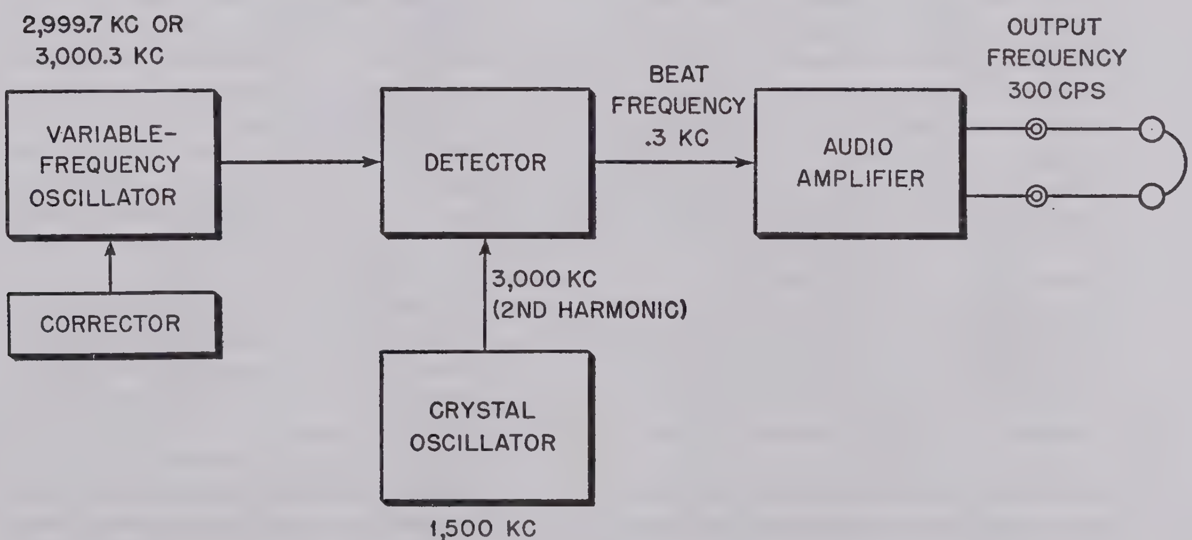


Figure 9. Typical arrangement for calibrating a frequency oscillator.

The circuit of tube V_1 is the variable-frequency oscillator whose output beats against the unknown frequency entering by way of the pick-up antenna. The circuit containing V_2 is the mixer stage to mix these signals, and serves also as a pentagrid converter when the variable oscillator is being calibrated. During calibration, the crystal oscillator is in the control-grid circuit of V_2 and the output of V_2 is fed to an a-f amplifier, V_3, which drives the headphones.

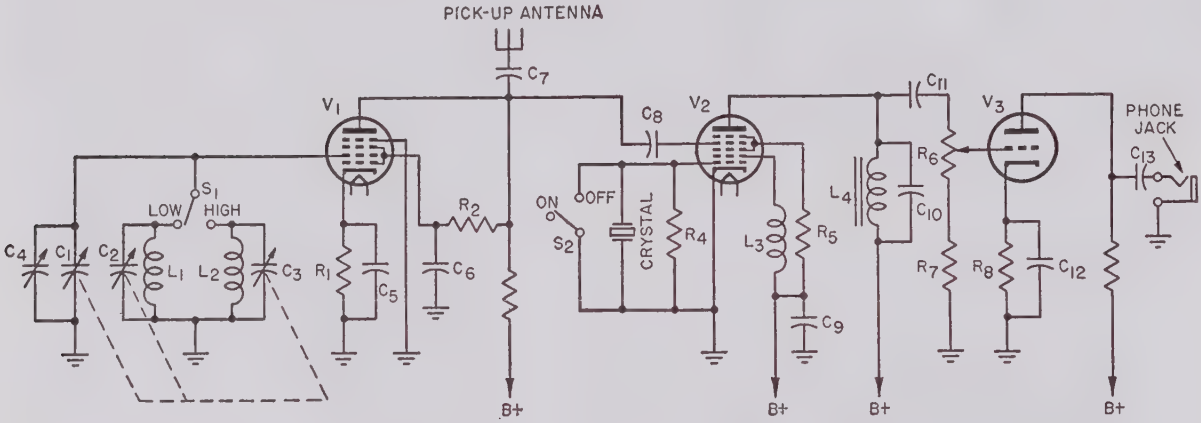


Figure 10 Basic practical circuit of heterodyne frequency meter.

(2) The circuit of V_1 forms an electron-coupled oscillator which has good stability under varying load conditions. Switch S_1 permits the oscillator to operate on two different frequency ranges. With S_1 in the low-frequency position, L_1C_2 determines the natural oscillator frequency. With S_1 in the high-frequency position, L_2C_3 determines the natural oscillator frequency. C_2 and C_3 are variable and cover the entire low- and high-frequency ranges, respectively. C_1 changes the natural frequency of the oscillator on both frequency ranges but to a lesser degree than C_2 and C_3. C_1, C_2, and C_3 are ganged together and are varied by the frequency tuning knob on the dial setting. C_4 is a trimmer capacitor that *corrects* for frequency deviation when the variable oscillator is being calibrated.

(3) With switch S_2 in the OFF position, the control grid of V_2 is grounded, and V_2 becomes a mixer stage. It mixes the output of V_1, which is coupled through capacitor C_8, and the unknown frequency, which is coupled through C_7. When it is desired to calibrate the variable oscillator, S_2 is placed in the ON position, and V_2 becomes a pentagrid converter with the cathode and the two grids directly above it, constituting a crystal oscillator, and the remaining electrodes forming a mixer stage. The output of V_2 is coupled through C_{11} to V_3, and the output of this tube is fed to the headphones. Resistor R_6 controls the the sound output in the headphones by varying the input voltage to V_3.

d. Control Panel.

(1) The control panel of a heterodyne frequency meter is shown in figure 11. When the LOCK screw is loosened, the tuning knob can be rotated to obtain various settings on the dial. The dial is calibrated in hundredths, units, and tenths for accurate readings. Rotating the dial changes the resonant frequency of the variable-frequency oscil-

lator by varying capacitor C_1, C_2, and C_3. When calibrating, the CRYSTAL OFF-ON switch, S_2, is turned to the ON position. The CORRECTOR control varies capacitor C_4 and compensates for any deviation of the variable-frequency oscillator. The FREQ BAND switch, S_1, selects the frequency range in which the meter is to be operated. Typical frequency ranges are 125 to 2,000 kc in the low-frequency band and 2,000 to 20,000 kc in the high-frequency band. The GAIN control, R_6, varies the intensity of the ouput signal heard in the headphones.

(2) The dial setting in figure 1 1 can be read in the following manner: The thin line marked on the window of the HUNDREDS dial indicates the *approximate* reading of the dial. Since it is situated between 3,800 and 3,900, the ultimate dial reading must lie between these numbers. The reading on the UNITS dial is read directly below the arrow on the TENTHS vernier. To obtain the reading, which lies between 76 and 77, the TENTHS vernier must be read. The tenths value is obtained from the dial by finding the line on its scale which coincides most closely with a line on the UNIT dial. The value of .7 on the TENTHS dial corresponds with 83 on the UNIT dial; therefore, the reading obtained on the dial setting shown in figure 1 1 is 3,800 plus 76 plus .7, or 3,876.7. The frequency reading that corresponds to this number must be obtained from a calibration book which is included with each frequency meter.

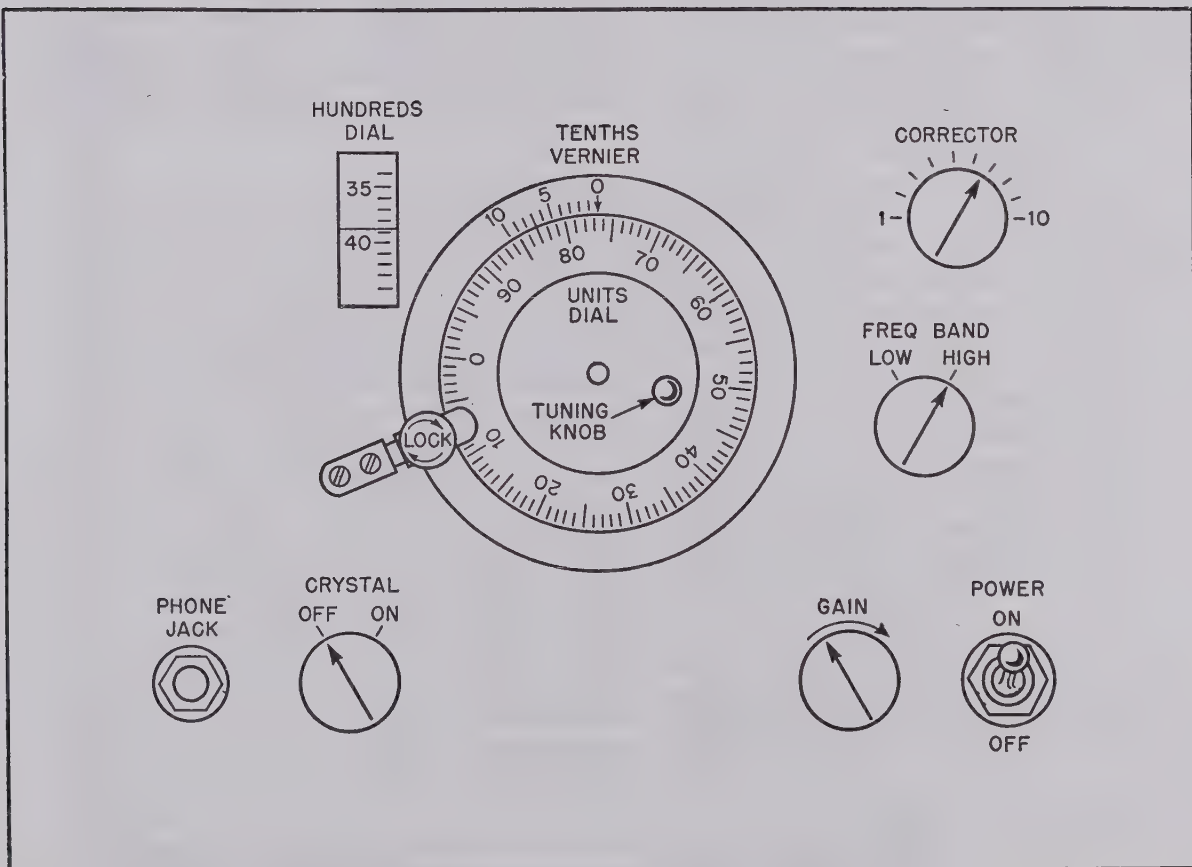


Figure 1 1 Typical control panel of heterodyne frequency meter.

e. CALIBRATION BOOK.

(1) Two typical pages of a calibration book are shown in figure 12. The pages are divided into DIAL and FREQUENCY columns and each dial setting corresponds to four different frequencies. The frequency column immediately following the dial setting represents the fundamental frequency of the variable oscillator. For example, a dial reading of 3,904.3 (fig. 12) indicates that the fundamental frequency of the variable oscillator is 3,660 kc. The other three frequency columns correspond to the harmonics generated by the variable oscillator. Consider an oscillator under test whose frequency output is approximately 14,000 kc. When determining its exact frequency output by means of a frequency meter, a dial reading of 3,942.2 is obtained. Looking in the third frequency column in the calibration book, the exact oscillator frequency is seen to be 14,704 kc.

(2) At the bottom of each page are the words NEAREST CRYSTAL CHECK POINT. The three numbers immediately following these words are the crystal check points nearest the desired frequency, and represent harmonics of the crystal oscillator.

(3) The observed dial setting may fall between two values listed in the calibration book. To aid in the calculation of the frequency corresponding to an intermediate dial setting, the following method, called interpolation, is used. The dial reading shown in figure 11 is 3,876.7. The calibration book (fig. 12) shows that this reading lies between the dial settings of 3,875.7 and 3,878.1.

	Dial setting	
	3,875.7	
diff = 2.4	3,876.7	
	3,878.1	diff = 1.4.

The fundamental frequencies of these two dial settings are 3,648 and 3,649 kc.

	Frequency	
	3,648	
Diff = 1 kc	*unknown freq.*	diff = x kc.
	3,649	

Therefore, a proportion is set up in the following manner:

$$\frac{1\ \text{kc}}{x\ \text{kc}} = \frac{2.4}{1.4}$$

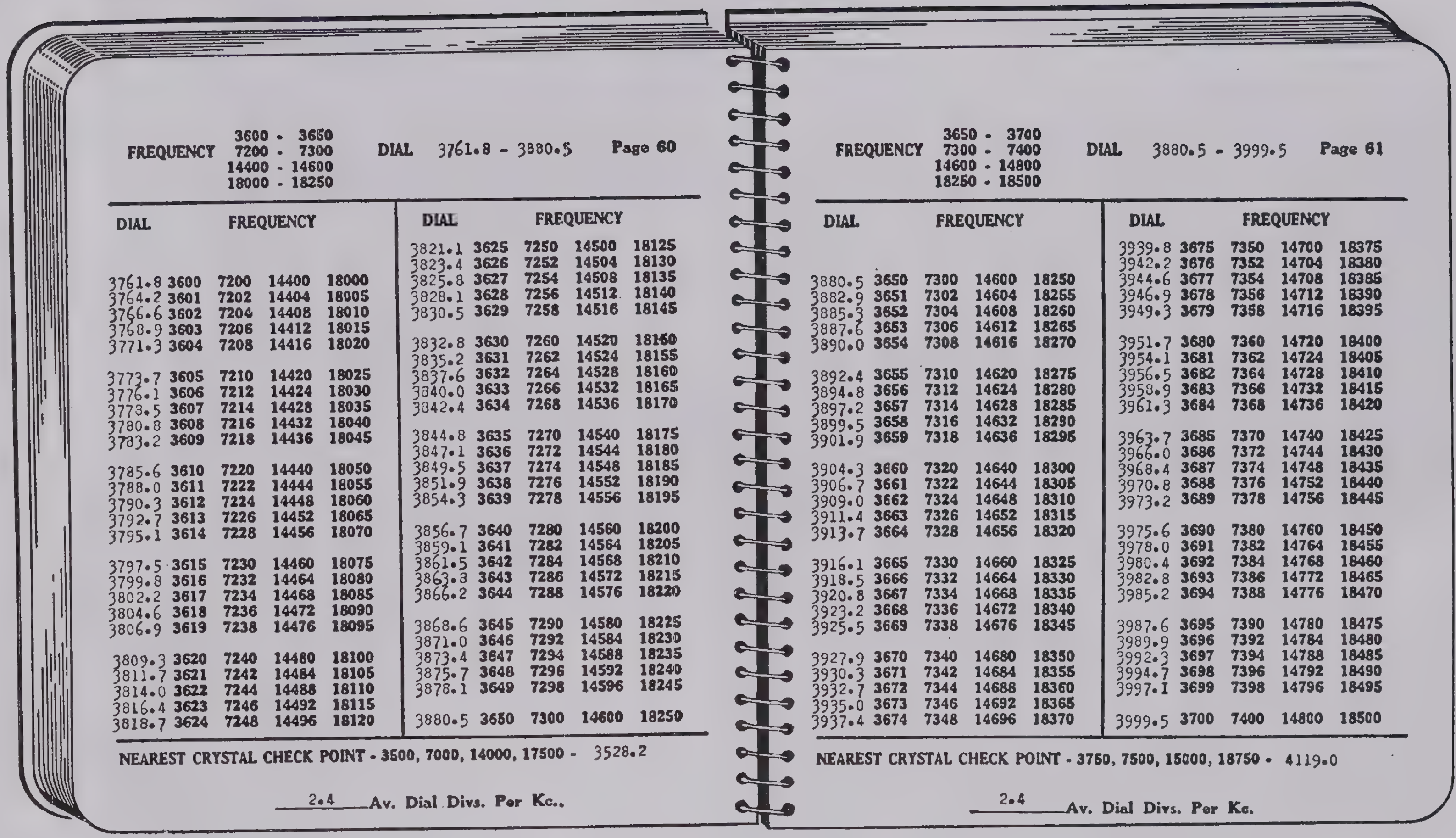
$$X = \frac{1.4}{2.4} = .583.$$

The unknown frequency is 3,649 minus .583, or 3648.417 kc. The last two significant figures can be discarded for all practical purposes.

f. USES. Frequency meters are used to check unknown frequencies and also to check or set the frequency of a receiver or a transmitter. To tune a transmitter to a desired frequency, find the page in the calibration book that shows the dial setting of the frequency to which the transmitter is to be tuned; with the crystal oscillator turned on, the frequency-meter dial then is set to the *nearest* crystal check point. The CORRECTOR control then is adjusted to obtain zero beat in the headphones, the crystal oscillator is turned off, and the frequency-meter dial is set to the desired frequency. The transmitter then is loosely coupled to the frequency meter and tuned until zero beat is obtained. An identical procedure is used when tuning a receiver or other equipment.

4. Secondary Frequency Standard

a. INTRODUCTION. The output frequency of the crystal oscillator used to calibrate a heterodyne frequency meter is called a standard frequency. It is a reference frequency with which the output of the variable oscillator is compared. Some equipments do not contain a crystal calibration oscillator within their units and another method of obtaining a standard frequency must be used. There are two methods of obtaining this frequency standard. The *primary* frequency standard uses radio signals sent out by a permanent transmitter, such as Station WWV at Arlington, Virginia. These signals are used as the standard frequencies for calibration of equipment and take the place of the crystal oscillator in a heterodyne frequency meter. The more common method is to use the crystal oscillator in a heterodyne frequency meter as a *secondary* frequency standard. This secondary frequency standard can be used to check the accuracy of any oscillator within its frequency



FREQUENCY 3600 - 3650, 7200 - 7300, 14400 - 14600, 18000 - 18250 DIAL 3761.8 - 3880.5 Page 60

DIAL	FREQUENCY			
3761.8	3600	7200	14400	18000
3764.2	3601	7202	14404	18005
3766.6	3602	7204	14408	18010
3768.9	3603	7206	14412	18015
3771.3	3604	7208	14416	18020
3773.7	3605	7210	14420	18025
3776.1	3606	7212	14424	18030
3778.5	3607	7214	14428	18035
3780.8	3608	7216	14432	18040
3783.2	3609	7218	14436	18045
3785.6	3610	7220	14440	18050
3788.0	3611	7222	14444	18055
3790.3	3612	7224	14448	18060
3792.7	3613	7226	14452	18065
3795.1	3614	7228	14456	18070
3797.5	3615	7230	14460	18075
3799.8	3616	7232	14464	18080
3802.2	3617	7234	14468	18085
3804.6	3618	7236	14472	18090
3806.9	3619	7238	14476	18095
3809.3	3620	7240	14480	18100
3811.7	3621	7242	14484	18105
3814.0	3622	7244	14488	18110
3816.4	3623	7246	14492	18115
3818.7	3624	7248	14496	18120

DIAL	FREQUENCY			
3821.1	3625	7250	14500	18125
3823.4	3626	7252	14504	18130
3825.8	3627	7254	14508	18135
3828.1	3628	7256	14512	18140
3830.5	3629	7258	14516	18145
3832.8	3630	7260	14520	18150
3835.2	3631	7262	14524	18155
3837.6	3632	7264	14528	18160
3840.0	3633	7266	14532	18165
3842.4	3634	7268	14536	18170
3844.8	3635	7270	14540	18175
3847.1	3636	7272	14544	18180
3849.5	3637	7274	14548	18185
3851.9	3638	7276	14552	18190
3854.3	3639	7278	14556	18195
3856.7	3640	7280	14560	18200
3859.1	3641	7282	14564	18205
3861.5	3642	7284	14568	18210
3863.8	3643	7286	14572	18215
3866.2	3644	7288	14576	18220
3868.6	3645	7290	14580	18225
3871.0	3646	7292	14584	18230
3873.4	3647	7294	14588	18235
3875.7	3648	7296	14592	18240
3878.1	3649	7298	14596	18245
3880.5	3650	7300	14600	18250

NEAREST CRYSTAL CHECK POINT - 3500, 7000, 14000, 17500 - 3528.2

2.4 Av. Dial Divs. Per Kc.

FREQUENCY 3650 - 3700, 7300 - 7400, 14600 - 14800, 18250 - 18500 DIAL 3880.5 - 3999.5 Page 61

DIAL	FREQUENCY			
3880.5	3650	7300	14600	18250
3882.9	3651	7302	14604	18255
3885.3	3652	7304	14608	18260
3887.6	3653	7306	14612	18265
3890.0	3654	7308	14616	18270
3892.4	3655	7310	14620	18275
3894.8	3656	7312	14624	18280
3897.2	3657	7314	14628	18285
3899.5	3658	7316	14632	18290
3901.9	3659	7318	14636	18295
3904.3	3660	7320	14640	18300
3906.7	3661	7322	14644	18305
3909.0	3662	7324	14648	18310
3911.4	3663	7326	14652	18315
3913.7	3664	7328	14656	18320
3916.1	3665	7330	14660	18325
3918.5	3666	7332	14664	18330
3920.8	3667	7334	14668	18335
3923.2	3668	7336	14672	18340
3925.5	3669	7338	14676	18345
3927.9	3670	7340	14680	18350
3930.3	3671	7342	14684	18355
3932.7	3672	7344	14688	18360
3935.0	3673	7346	14692	18365
3937.4	3674	7348	14696	18370

DIAL	FREQUENCY			
3939.8	3675	7350	14700	18375
3942.2	3676	7352	14704	18380
3944.6	3677	7354	14708	18385
3946.9	3678	7356	14712	18390
3949.3	3679	7358	14716	18395
3951.7	3680	7360	14720	18400
3954.1	3681	7362	14724	18405
3956.5	3682	7364	14728	18410
3958.9	3683	7366	14732	18415
3961.3	3684	7368	14736	18420
3963.7	3685	7370	14740	18425
3966.0	3686	7372	14744	18430
3968.4	3687	7374	14748	18435
3970.8	3688	7376	14752	18440
3973.2	3689	7378	14756	18445
3975.6	3690	7380	14760	18450
3978.0	3691	7382	14764	18455
3980.4	3692	7384	14768	18460
3982.8	3693	7386	14772	18465
3985.2	3694	7388	14776	18470
3987.6	3695	7390	14780	18475
3989.9	3696	7392	14784	18480
3992.3	3697	7394	14788	18485
3994.7	3698	7396	14792	18490
3997.1	3699	7398	14796	18495
3999.5	3700	7400	14800	18500

NEAREST CRYSTAL CHECK POINT - 3750, 7500, 15000, 18750 - 4119.0

2.4 Av. Dial Divs. Per Kc.

Figure 2 Two pages of typical calibration book.

range and does not require a separate piece of equipment for calibration purposes.

b. BLOCK DIAGRAM. A block diagram of a secondary frequency standard is shown in figure 98. When the INTERVAL switch is in the 1,000-kc position, the 1,000-kc crystal oscillator and buffer amplifier feed the harmonic amplifier. The harmonic amplifier is used to amplify the harmonics fed from the 1,000-kc oscillator and the 100-, 25- and 10-kc multivibrators. The output of the harmonic amplifier then beats against the external signal input in the mixer amplifier. If the difference frequency is in the audio range, it is heard in the headphones. If the frequency of the external signal input equals the fundamental frequency, or a harmonic of the 1,000-kc crystal oscillator, no sound is heard in the headphones. For example, if the external frequency is 2,000 kc, the second harmonic of the oscillator will beat with it, and because the difference frequency is zero no ouput will appear in the headphones. However, if the signal is 2,010 kc or 1,090 kc, there is a 10-kc difference between the two frequencies and a high-pitched 10,000-cycle beat note will appear in the headphones. When the signal is 2,020 kc or 1,080 kc, the difference frequency is 20,000 cycles and the signal again cannot be heard in the headphones because it is above the audible range. As the difference frequency approaches the audible range, a high-frequency beat note is heard that gradually decreases in frequency until the zero-beat frequency is reached. If the signal is tuned past the zero-beat frequency, a low-frequency note appears that gradually increases in pitch until the audible range of frequencies is past, and the signal is no longer heard in the headphones. When the INTERVAL switch is in the 100-kc position, a 100-kc multivibrator feeds the harmonic amplifier. On the 25- and 10-kc positions, a 10- and 25-kc multivibrator feeds the harmonic amplifier. The multivibrators produce signals at 100-, 10-, and 25-kc intervals to extend the range of the secondary frequency standard, and are synchronized by the 1,000-kc crystal oscillator. The tone modulator is an audio-frequency oscillator that can be connected to the harmonic amplifier by a switch when a modulated signal is required at the output.

c. FRONT VIEW OF SECONDARY FREQUENCY STANDARD.

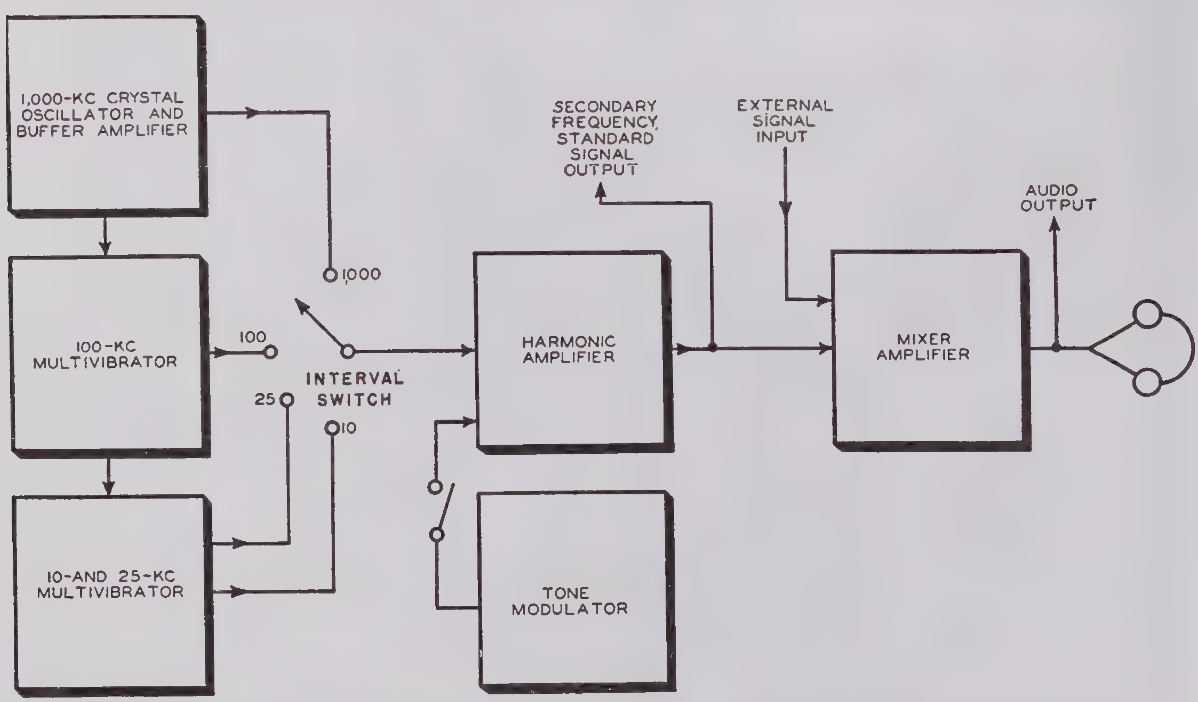


Figure 13 *Block diagram of typical secondary frequency standard.*

(1) The INTERVAL switch, located on the right side of the secondary frequency standard panel (fig. 13), is used to select the low-frequency oscillator harmonic output at the desired intervals. The ZERO SET adjustment varies the 1,000-kc crystal oscillator frequency a few cycles in either direction to compensate for temperature changes. Ordinarily, it is used only when checking the secondary frequency standard against a primary frequency standard. The BAND switch located at the lower left corner of the panel permits selection of any one of six frequency bands. The total frequency coverage of this secondary standard is from 10 kc to 50 mc.

(2) The AMP TUNE control (lower center of panel) is used to adjust the output level of the harmonic amplifier. There are three switches at the bottom of the panel. The FIL switch turns on all the filaments and the pilot light. The PLATE switch applies the plate voltage to all tubes. The MOD switch makes a 900-cps note available when a modulated signal is required. The GAIN controls the level of r-f output of the secondary standard as well as the volume of the beat-frequency output available at the PHONE jack. It also controls the level of the r-f input signal applied to the mixer amplifier through the INPUT terminals.

d. Uses. The secondary frequency standard is used to determine an unknown frequency or to calibrate a transmitter or receiver. The secondary frequency standard is used also to calibrate wavemeters, signal generators, oscilloscopes, and heterodyne frequency meters

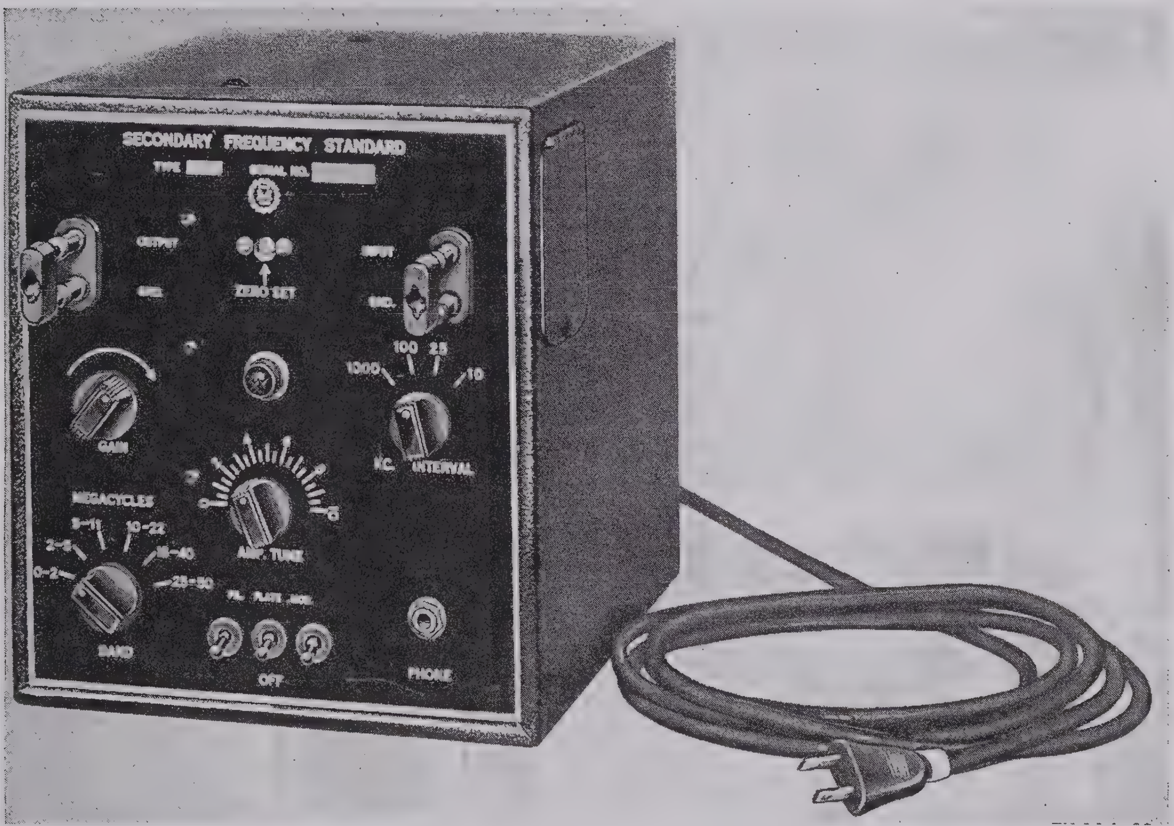


Figure 14. Typical secondary frequency standard.

which do not contain a calibrated crystal oscillator.

5. Summary

a. A *wavemeter* is a frequency meter which contains a variable tuned circuit whose resonant frequency is made to equal the unknown frequency.

b. A reaction wavemeter absorbs very little power from the equipment whose frequency is to be measured. An indicating device (usually an ammeter) is located in the circuit whose frequency is to be measured.

c. An *absorption* wavemeter absorbs a small quantity of power from the equipment whose frequency is to be measured. An indicating device, such as an ammeter, a lamp, or an earphone in the wavemeter, is used to indicate the unknown frequency.

d. Loose coupling is ideal for frequency measurements, since the indication at resonance is very sharp.

e. A micrometer consists of a thimble containing a vernier scale which is rotated about a barrel containing a coarse scale.

f. A *heterodyne,* or *beat,* frequency meter generates signals of known frequencies and compares them with an unknown frequency.

g. In a heterodyne frequency meter, when the known and unknown frequencies are equal a *zero-beat* frequency results.

h. The points at which the variable oscillator in a heterodyne frequency meter can be calibrated with a crystal oscillator are known as *crystal check points.*

i. The frequency corresponding to the dial setting on a frequency meter is obtained in a *calibration* book or chart.

j. When calibrating an oscillator by the primary frequency standard method, radio signals sent out by a permanent transmitter at specific frequencies are used as the calibration points.

k. When calibrating an oscillator by the secondary frequency standard method, a separate piece of equipment is used to transmit specific frequencies which are used as the calibration points.

l. A secondary frequency standard is used to determine an unknown frequency or to calibrate a transmitter or receiver which does not contain a crystal oscillator.

6. Review Questions

a. Give two uses of a frequency meter.

b. Explain the difference between an absorption wavemeter and a reaction wavemeter.

c. How does coupling affect the operation of a reaction wavemeter?

d. Why is loose coupling desirable in frequency measurements?

e. Draw a block diagram of an absorption wavemeter using headphones as an indicating device.

f. Explain how an unknown frequency is determined by means of a reaction wavemeter.

g. What is meant by a zero-beat frequency?

h. Explain the basic principle of operation of a heterodyne frequency meter.

i. What are crystal check points?

j. What is a primary frequency standard?

k. What is a secondary frequency standard?

l. Why is a secondary frequency standard used?

BASIC FUNDAMENTALS OF

ELECTRONIC TEST EQUIPMENT

CONTENTS

BASIC FUNDAMENTALS OF ELECTRONIC TEST EQUIPMENT

I. THEORY OF METERS

. Importance of Test Equipment

A technician may be required to put new pparatus in operation, to maintain equipment o that it continues to operate, and to repair quipment that has broken down. Many test nstruments are available to help him to do nese jobs efficiently. To place in operation and naintain new apparatus he is aided by test quipment such as signal generators, voltneters, ammeters, frequency meters, and outut meters. When there is a breakdown, multineters, vtvm's (vacuum-tube voltmeters), sigal tracers, tube checkers, and other devices elp locate the trouble quickly and efficiently fig. 1). Since the technician must understand ow these devices work and how to use them orrectly, this manual describes the theory and se of nearly every important radio test inrument. Meters are the most commonly used f all test equipment and, therefore, a brief utline of the different kinds is given in this napter.

. Basic Meter Principles

a. PURPOSE. Meters are used to measure ectrical quantities. Some meters measure voltge, current, resistance, or all three. Others neasure power, capacitance, or other electrical uantities. Whatever the meter is designed to neasure, its operation depends (except in an ectrostatic meter) on the passage of an elecric current through it.

b. USE OF CURRENT METERS. Since meters annot indicate measurements without a flow of urrent through them, it might seem that they an be used only to measure current. This is ot true. A meter circuit can be modified and ne meter calibrated to read almost any of the asic electrical units. For example, a meter an be used to measure voltage even though it registers only because of the current through it. It is possible to do this because the current through the meter varies in exact proportion to the voltage across the circuit (Ohm's law). The face of the meter then can be calibrated in volts rather than in amperes. Also, the amount of resistance in a circuit directly affects the current in the circuit, and, if desired, the meter can be calibrated in resistance units instead of current or voltage units.

c. PROPERTIES OF CURRENT FLOW. Two fundamental properties of current flow—*electromagnetism* and *heat*—are used to make meters function.

(1) When current flows through a coil, a magnetic field is created that is directly proportional to the amount of current. The strength of this field can be used in several different ways to indicate the amount of current passing through the coil. Three classes of meters use electromagnetism: *moving-iron* meters, *moving-coil* meters, and *dynamometers*.

(2) When current flows through a wire, the amount of heat produced is directly proportional to the current flow. Consequently, the amount of heat can be used to indicate the amount of current. Meters using this principle are called *thermal* meters. The two main classes are *hot-wire ammeters* and *thermocouple* meters.

3. Electromagnetic Meters

a. MOVING-IRON METERS.

(1) *Basic principle.* If a soft-iron bar is placed near an electromagnet, the bar becomes magnetized (fig. 2). The molecules of the bar line up, and the lines of force through the bar are in

the same direction as the lines of force coming from the electromagnet. Since the lines of force act like stretched rubber bands, they try to shorten themselves, and the bar is attracted to the electromagnet. If the coil is fixed and the bar is free to move, the bar is pulled into the coil. When the current through the coil reverses, the molecules in the iron bar reverse. The reversed lines of force in the bar line up with the reversed lines of force coming from the coil, and the bar again is attracted to the coil. The soft-iron bar therefore is attracted to the electromagnet whether dc (direct current) or ac (alternating current) flows through the coil. Soft iron is used because it demagnetizes when the current through the electromagnet stops. There are two types of moving-iron meters—the *plunger-type* and the *repulsion-type moving vane.*

(2) *Plunger type.* The movable soft-iron bar with a pointer attached is placed partially inside the fixed coil (fig. 3), and the pointer-bar assembly is fastened to a pivot, A. When current flows through the coil, a magnetic field is set up. The soft-iron bar becomes magnetized and is pulled farther into the coil, moving the pointer. The distance the pointer is moved is proportional to the strength of the magnetic field, which depends on the amount of current through the coil. The plunger type was an early meter used to measure ac and is now obsolete.

(3) *Repulsion-type moving vane.* This meter, like the plunger type, operates on the principle that an electromagnet magnetizes soft iron. Two iron bars are used instead of one, and both are placed completely inside the coil. When current flows, the bars are magnetized with the same polarity (fig. 4) and,

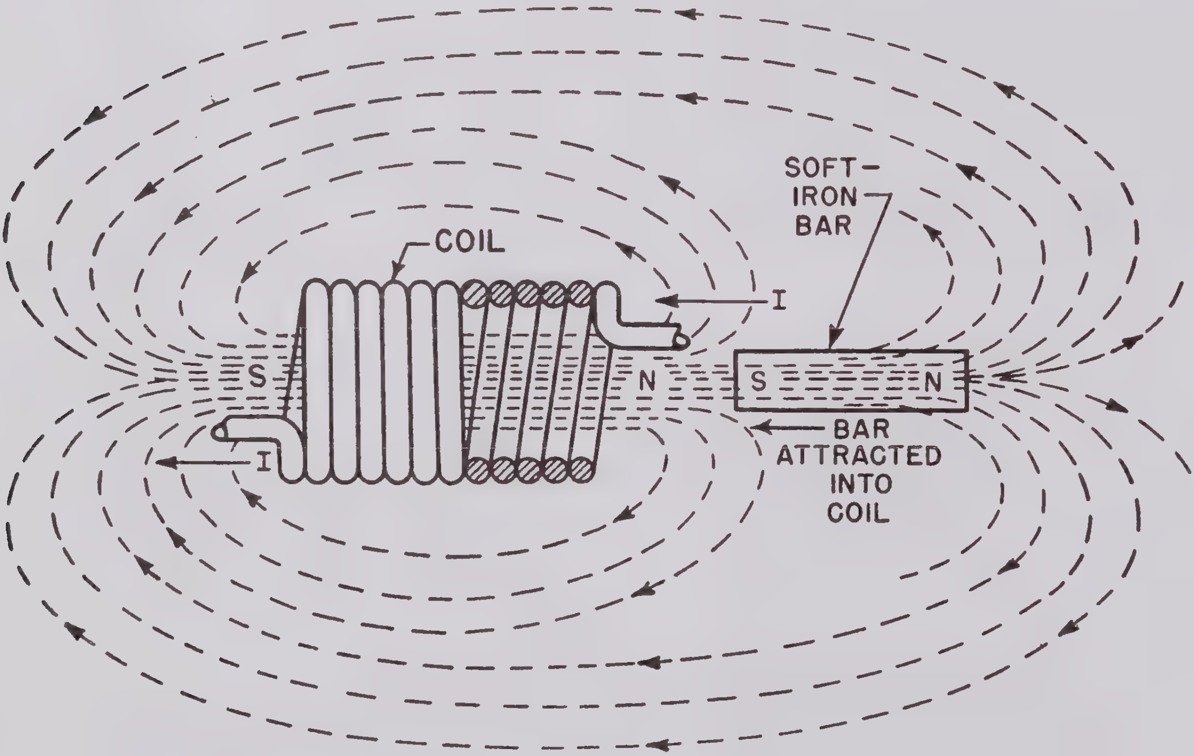


Figure 2. Effect of lines of force from current-carrying coil on soft iron bar.

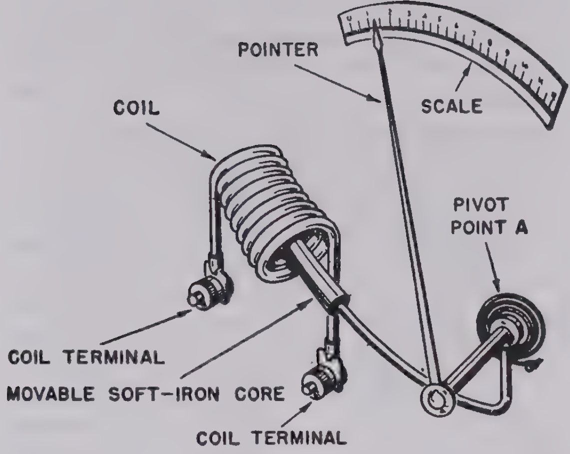


Figure 3. Moving-iron meter, plunger type.

because like poles repel, the bars move apart. If the current reverses, the polarity of the bars reverses at the same time, and they still repel each other. When one bar is fixed and the other free to move, the force of repulsion can be made to indicate the amount of current flow by attaching a pointer to the movable bar. Two groups of meters use the repulsion principle. They are the *radial-vane* and the *concentric-vane* meters.

(*a*) In the radial-vane meter, two rectangular vanes are placed inside the coil (fig. 5). One vane is fixed, and the other is free to rotate on pivots and has a pointer attached. When current flows through the coil, the iron vanes become magnetized and repel each other. The movable vane swings away, carrying with it the pointer that indicates on the scale the current passing through the coil.

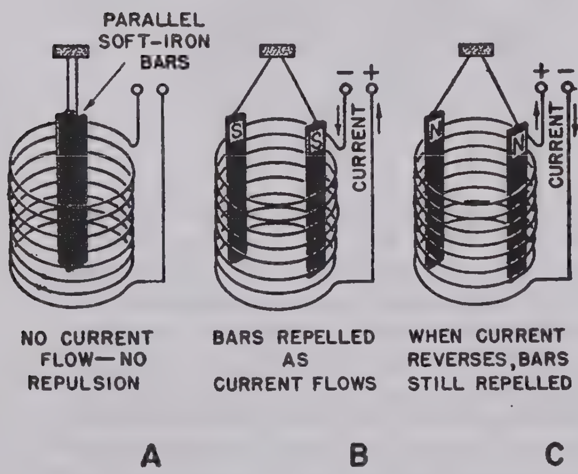


Figure 4. Effect of iron bars in electromagnet.

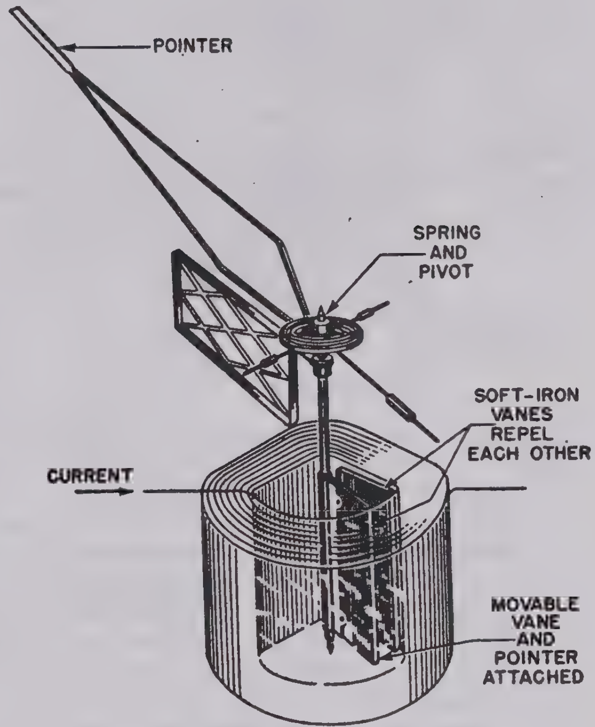


Figure 5. Radial-vane meter.

(*b*) The concentric-vane meter works on the same general principle and is described as concentric because the semicircular vanes are placed one inside the other (fig. 6). One vane is fixed and the other is free to move on pivots, with a pointer attached. Although repulsion-type meters can be made to measure ac or dc, they are used generally to measure low-frequency ac.

b. Moving-Coil Meter.

(1) Most of the meters used by technicians embody the moving-coil principle of

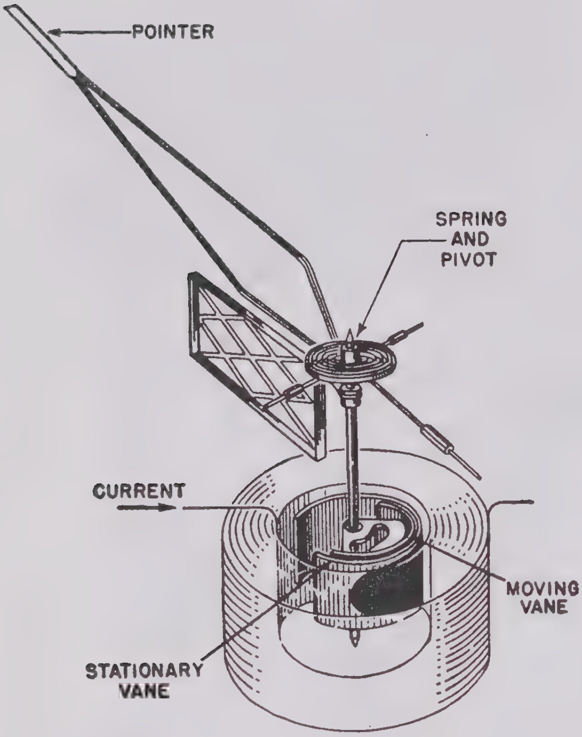


Figure 6. Concentric-vane meter.

operation. The moving-coil meter uses a coil of fine wire wound on a light aluminum frame with a permanent magnet surrounding the coil (fig. 7). The coil is placed on pivots on the ends of the frame which allows the coil to move freely, and springs are attached to it to control the amount of needle swing. When current flows through the coil, it becomes magnetized, and the polarity of the coil is such that it is repelled by the permanent magnet. A pointer attached to the coil frame swings with the coil, and indicates on the scale the amount of current flowing through the coil. This meter movement can be made so sensitive that a few microamperes of current will swing the pointer across the entire scale. If the pointer and zero indication are placed at the center of the scale, the movement can be used for making accurate resistance, capacitance, and inductance measurements in bridges and can be modified for use as a *d-c ammeter* or a *voltmeter*. It can be made to measure ac by applying the ac to the meter through a suitable rectifier, and measuring the rectified current.

(2) Because the moving-coil meter is rugged, accurate, and capable of measuring d-c voltage and current, a-c voltage, and also resistance, it is used invariably in the *multimeter*, a combination volt-ohm-ammeter. This meter movement is used also in the vtvm and is by far the most important type of meter in radio and electrical work.

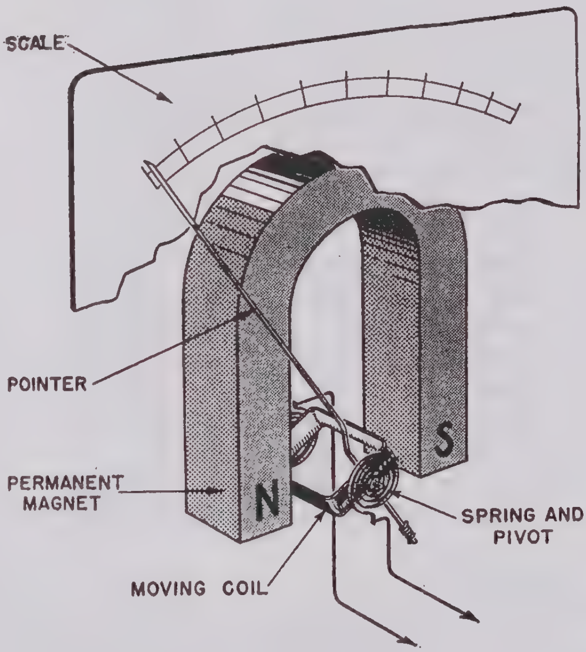


Figure 7. Moving-coil meter.

c. DYNAMOMETER. The *dynamometer* is based on the principle of magnetic repulsion between two or more electromagnetic fields. When two coils are used, one is fixed and the other has a pointer attached and is pivoted for free movement. Current passes through both coils, and magnetic fields are created. The movable coil, with the attached needle, is repelled by the like poles of the fixed coil and swings away, carrying the pointer with it. The dynamometer can measure a-c and d-c voltage, current, and power,

although it is used commonly to measure power in watts (fig. 8). When used as a wattmeter, two fixed coils wound with many turns of small wire and having a high resistance are connected in series across the voltage source of the circuit. A movable, low-resistance coil is placed in series with one connection, and the entire circuit current flows through it. The strength of the field around the low-resistance coil depends on the current in the circuit. The low-resistance movable-coil and indicating-needle (pointer) assembly swings a distance proportional to the *combined* strength of the two magnetic fields. The swing therefore is proportional to both the current and the voltage in the circuit. Since power also is proportional to the current and voltage, the meter can be calibrated in watts, the unit of power.

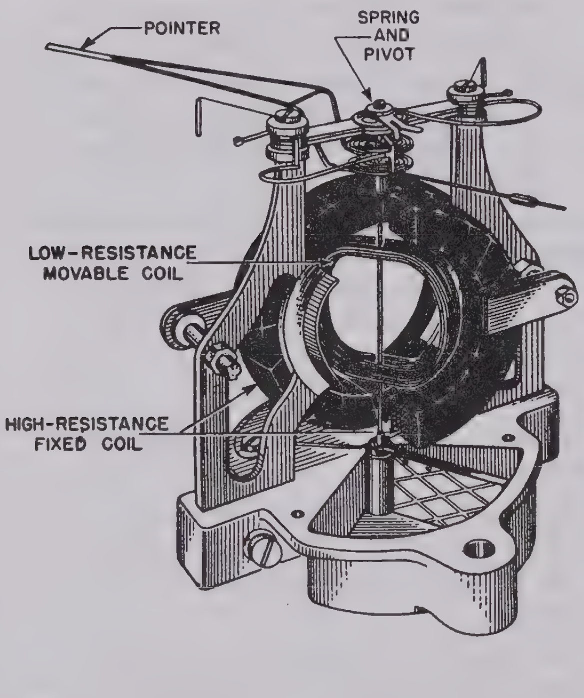


Figure 8. Dynamometer. Low-resistance movable coil with two high-resistance fixed coils.

4. Thermal Meters

a. Hot-Wire Ammeter. The heat generated by current flowing in a wire will cause the wire to expand. In the hot-wire ammeter the expanding wire moves a pointer which indicates the current in the circuit on the scale of the meter. The meter is connected in series with the load by means of terminals A and B (fig. 9). Within the meter, wire 1 is connected between the two terminals. Wire 2 is attached to the first wire near the center and the amount of tension applied to wire 1 is controlled by the tension spring. Wire 2 passes along the round base of a pivoted indicating needle and is used as a drive wire to move the needle. When current passes through wire 1, the heat is proportional to the strength of the current. The higher the current, the greater the heat generated and the more wire 1 expands. As wire 1 expands, it is pulled down by the tension of the spring and wire 2 rides along the base of the pivoted needle, driving the needle across the scale. The needle is adjusted to read 0 with 0 current by means of the adjustment screw regulating the sag in wire 1.

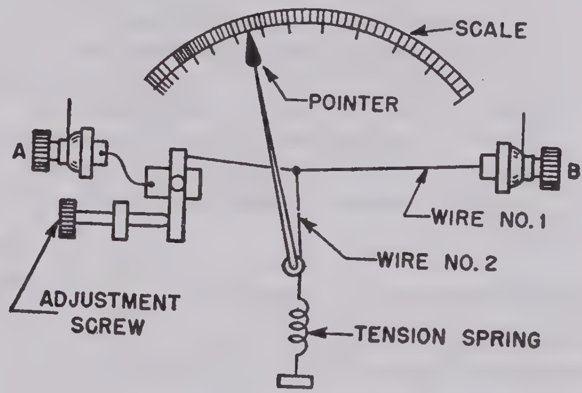


Figure 9. Hot-wire ammeter.

b. Thermocouple Meter.

(1) If 1 ampere of current flows through a wire, a certain amount of heat is produced. The quantity of heat is exactly the same for 1 ampere of current whether the current is low-frequency ac, high-frequency ac, or dc. The thermal effect therefore can be used to measure any kind of current. Thermocouple meters generally are used to measure high-frequency ac. The thermocouple meter is used in transmitters to measure r-f (radio-frequency) antenna current and r-f power.

(2) The thermocouple meter is placed in series with the circuit under test, so

that the circuit current passes through wire A of the meter (fig. 10). Wire A is attached to the junction of two different metals, and this bimetallic strip forms the *thermocouple.* The thermocouple has the property of generating a d-c voltage when the junction of the dissimilar metals is heated. The current heats the wire, the hot wire heats the thermocouple, and a small d-c voltage is generated which appears across terminals C and D, and is proportional to the amount of heat. Within limits of the thermocouple, the more current in the circuit the more heat at the junction, and the greater the d-c voltage generated. The voltage across C and D then is applied to a moving-coil d-c meter. It should be emphasized that either ac or dc can be sent through wire A to heat the thermocouple. *Whatever the kind of current passing through the wire and being measured, only d-c voltage appears at the free ends of the thermocouple.* The thermocouple meter can be said to combine both the thermal and the electromagnetic principles of operation.

5. General Meter Considerations

a. The meters described above can be used to measure either ac or dc by modifying the meter circuits and calibrating the meter scale in terms of the desired unit. The repulsion or moving-vane meter commonly is used for a-c measurements. In electrical and radio work, thermocouple meters are used exclusively for r-f measurements; moving-coil meters are used for almost all other measurements. The detailed discussion of these meters in the following chapters includes the advantages and limitations of each type. Information will be given on the meter characteristics listed below.

(1) *Accuracy.* Some meters are basically more accurate than others.

(2) *Interference with circuit operation.* Some meters, when connected in a circuit under test, alter the circuit conditions. The changes caused by the meter result in inaccurate measurements. Other meters have practically no effect on the circuit under test, and give more accurate readings.

(3) *Scale used.* Scales on some meters are linear, (with even spaces between numbers); other meters have nonlinear scales.

b. With this information, the technician can determine the best type of meter for a given purpose. In emergencies, he also will know how to modify any type of meter to suit his needs.

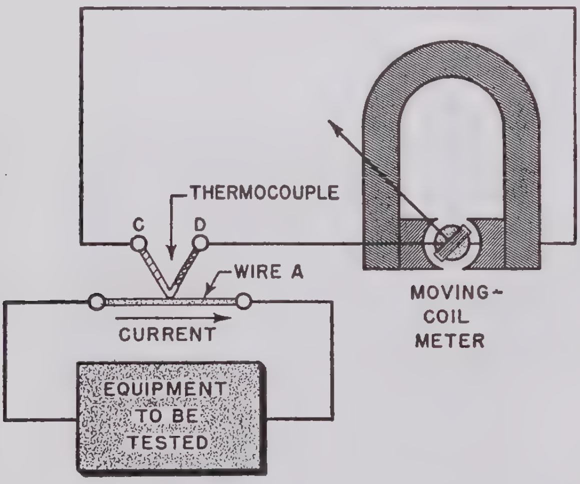


Figure 10. Thermocouple-type meter.

6. Summary

a. Meters are used to measure electrical quantities.

b. All meters, except electrostatic meters, regardless of the unit being measured, are operated by current flowing through the meter movement.

c. The fundamental properties of current flow used to make meters function are electromagnetism and heat.

d. Three classes of meters use the electromagnetic principle: moving-iron meters, moving-coil meters, and dynamometers.

e. Two classes of meters use the thermal principle: hot-wire ammeters and thermocouple meters.

7. Review Questions

a. What is the purpose of test equipment?

b. What are meters used for?

c. What is meant by the calibration of a meter?

d. What do most meters actually measure?

e. How can meters be used to measure various electrical quantities?

f. What are two basic properties of current flow?

g. What are the two main meter types?

h. Name the principal classes of meters under each basic type.

i. What is the basic principle used in moving-iron meters?

j. How is this principle applied in plunger-type meters?

k. Explain how this principle operates in repulsion-type moving-vane meters.

l. Explain the operation of moving-coil meters.

m. What kind of measurements can be made with moving-coil meters?

n. How do dynamometers operate?

o. Explain the operation of a hot-wire ammeter.

p. Outline the operation of a simple thermocouple meter.

q. Where are thermocouple meters usually found? Why?

II. D-C AMMETERS AND VOLTMETERS

8. Construction and Operation of Moving-Coil Meter

a. D'ARSONVAL MOVEMENT. The meter most commonly used in radio and electrical work is the moving-coil meter, preferred because of its accuracy, ruggedness, and linear scale. In 1882, Arsene d'Arsonval, using the moving-coil principle, developed a galvanometer, which is simply an unmodified meter movement measuring very small currents. In 1888, Dr. Edward Weston modified the design considerably to make the meter easily portable. The basic movement still is referred to as the d'Arsonval movement.

b. CONSTRUCTION.

(1) The moving-coil meter uses a horseshoe permanent magnet with soft-iron, semicircular pole pieces added to its ends (A, fig. 11). The magnet has a strong *nonuniform* magnetic field between the pole pieces that is not suitable for meter operation. A circular soft-iron core inserted between the pole pieces, however, results in a strong, *uniform* magnetic field in the spaces, and also helps the permanent magnet to retain its magnetism by acting as a keeper.

(2) The moving coil consists of several turns of fine wire wound on a rectangular aluminum frame (B, fig. 11). Because the coil must be light and able to swing freely, only a limited number of turns can be placed on the frame. The fine wire allows the coil to carry only a small amount of current and this amount varies with different models. Very little current is necessary to cause a full-scale deflection of the needle.

(3) The coil assembly is mounted in the air space between the pole pieces of the permanent magnet and the soft-iron core. Hardened-steel pivots are attached to the frame at the points where the springs are located, and the pivots fit into jeweled bearings, allowing the coil to turn with a minimum of friction (C, fig. 11). The indicating needle is attached to the coil assembly, swinging with it, and tiny counterweights are used to balance the assembly on its pivots. The two ends of the coil are connected to two springs, one on each side of the aluminum frame. The other ends of these springs go to the external circuit, from which current is fed to the coil. A screw on the front of the movement zero-adjusts the pointer to zero-scale reading for zero current (D, fig. 11).

c. BASIC OPERATING SYSTEMS. The moving-coil meter includes three basic systems in its overall operation:

(1) *Motor system.* The pointer must indicate the amount of current passing through the meter. This is accomplished by the motor system. When dc passes through the coil, the coil becomes magnetized, and is repelled by the permanent magnet. The pointer, swinging with the coil, registers a reading on the scale according to the amount of current flowing through the coil. The greater the current, the stronger the magnetic field around the coil, the greater the repulsion, and the farther the coil and pointer move. When current passes through the coil in the opposite direction, an opposite magnetic field is set up and the coil

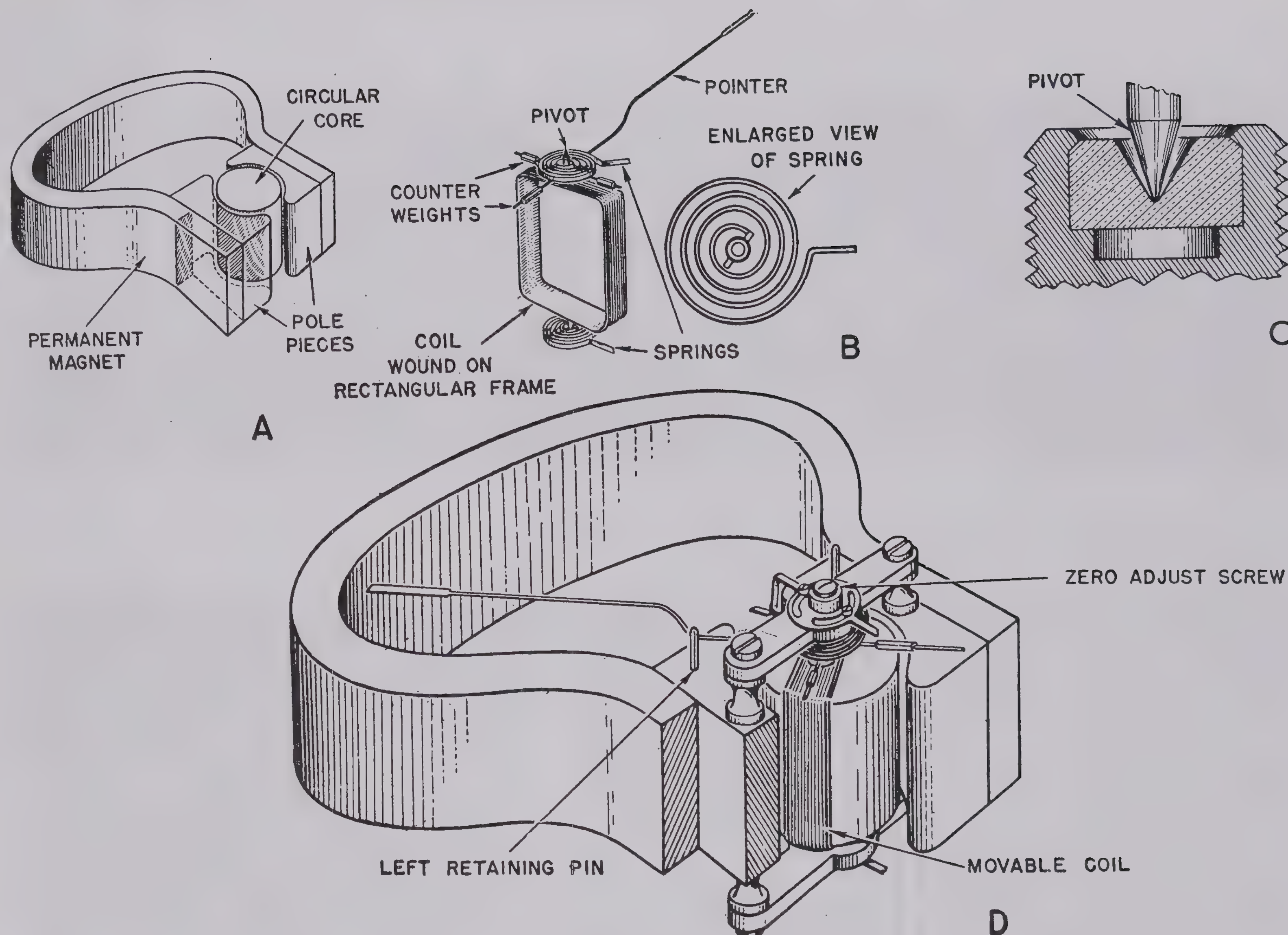


Figure 11. Component units of moving-coil meter movement.

is repelled in the opposite direction. The needle moves *backward,* hitting against the left retaining pin instead of moving to the right across the scale. Current, therefore, must be applied to the meter with the correct polarity so that the coil will turn the needle in the right direction. The needle cannot swing off-scale on the extreme right because of the right retaining pin.

(2) *Control system.* The pointer must indicate accurately the amount of current passing through the coil and return to 0 when the meter is removed from the circuit. These two operations are governed by the control system. The springs connected to the coil furnish the control action in the meter because:

(*a*) They regulate the amount of rotating action by the coil. For this reason they must be made with precision if the meter is to register accurately.

(*b*) They bring the coil and needle back to the 0 position when current through the coil stops flowing.

(*c*) They conduct current to and from the coil.

(*d*) They are oppositely wound to compensate for temperature changes. When current flows and the coil turns, one spring tightens as the other loosens. When the meter is removed from the external circuit, current through the coil stops flowing. Both springs return to their normal position, bringing the coil back to the 0 point. It is not necessary to wind springs in opposite directions to bring the coil back to 0. The advantage of oppositely wound springs lies in their compensating action when the temperature changes. A change of temperature causes the springs either to contract or expand. If both springs contract (or both expand), one spring tries to move the coil in one direction; the other, oppositely wound, tries to move it in the other direction. Because they are matched springs, their actions cancel and the needle remains at the 0 position. This makes it unnecessary to zero-set the meter every time there is a change of temperature. The springs usually are made of nonmagnetic phosphor bronze, and have a low resistance to current flow. Since the springs are good conductors, they are used to carry the current from the coil assembly to the external connections of the meter. Moving-coil meters have a zero-adjust screw which physically moves one spring (D, fig. 11) and varies the position of the coil and needle to some extent. If the needle is not on 0 when there is no current flowing through the meter, it should be zero-set by adjusting this screw before any readings are taken.

(3) *Damping system.* The needle must come to rest quickly at the correct point without vibrating. The method used to accomplish this is called damping. The damping system varies with different types of meters.

(*a*) *Damping action.* The object of damping is to get quick, correct indications from the pointer without having it swing back and forth before coming to rest. Damping is the equivalent of *braking* action on the needle swing. In the moving-coil meter, damping usually is accomplished by the aluminum frame on which the coil is wound. When the coil moves to register current flow, the aluminum frame itself acts like a one-turn coil. This frame cuts across the magnetic lines of force from the permanent magnet and a voltage is induced in it. Large eddy currents flow through the frame and set up a magnetic field around it which opposes the magnetic field of the permanent magnet. The braking action which results slows the

movement of the coil. As soon as the coil comes to rest, no further voltage is induced in the aluminum frame, and eddy currents no longer flow. When the coil returns to the zero position, the same process takes place in the aluminum frame. Briefly, eddy currents induced in the frame create a magnetic field that opposes the field of the permanent magnet and tends to oppose or brake the action of the springs in returning the coil to zero.

(b) *Ammeter damping.* A low-value resistance called a shunt is placed in parallel with the meter movement when it is to be used as an ammeter. Since the shunt parallels the meter movement, the current flows through both the meter coil and the shunt. When the coil starts to turn, the counter emf generated in it bucks the original current, and acts to cut it down until the coil stops moving. The counter emf gradually decreases and the current through the coil gradually increases toward its normal value until the coil comes to rest. The current through the shunt momentarily varies to compensate for the changes of current through the coil. When the meter is removed from the external circuit, the coil starts to return to zero, cutting the lines of force, and a voltage is generated across it. Since there is a shunt across the coil which closes the circuit through it, current flows momentarily from one end of the coil through the shunt to the other end of the coil and back again. This results in a magnetic field that bucks the field of the permanent magnet and acts as a brake on the return motion.

11. Meter Characteristics

a. INTERNAL RESISTANCE. Every meter coil has a definite amount of d-c internal resistance which depends on the number of turns on the coil and on the size of the wire used. When more windings are placed on the coil, a smaller amount of current is necessary to create a magnetic field strong enough to deflect the coil full scale.

b. SENSITIVITY OF METER MOVEMENT. Meter sensitivity can be defined in two ways—as the amount of current necessary for full-scale deflection and as the ohms per volt. The amount of current necessary for full-scale deflection depends on the number of turns on the coil. When more turns are added, a stronger magnetic field is created and a smaller amount of current is necessary for full-scale deflection. Sensitivities vary from 5 μa (microamperes) to approximately 50 ma (milliamperes) and the smaller the amount of current necessary for full-scale deflection of the meter, the greater the sensitivity. The sensitivity in ohms per volt is determined by the amount of resistance that must be placed in series with the meter to cause full-scale deflection when 1 volt is applied. The more resistance placed in series with the meter, the greater the sensitivity in ohms per volt. Internal resistance may vary from a fraction of an ohm to several hundred ohms, but is usually small enough to be disregarded. *Sensitivity and internal resistance are characteristics of the meter movement itself. They cannot be altered unless the construction of the movement is changed.*

c. ACCURACY.

(1) Moving-coil meters made for laboratory use have a very high accuracy (.1 of 1 percent), and some semiprecision meters are accurate to .5 of 1 percent. The accuracy of meters for general use, however, is within 2 percent. The *accuracy percentage* refers only to full-scale readings on any range. For example, a meter is rated as being accurate within 2 percent on the 500-volt range. At full-scale deflection, the reading will be accurate within 2 percent, or within ±10 volts. Actually, if a lower voltage is read on that scale, and is 10 volts off, the inaccuracy becomes greater than 2 percent. The smaller the reading, the greater will be the percentage of inaccuracy. Most meters, however, give a greater degree of accuracy along the scale than is

guaranteed. It should be remembered that the accuracy of voltage and current readings on moving-coil meters tends to be greater when the readings are taken closer to full-scale deflection.

(2) When a meter is inserted in a circuit, an interesting point sometimes arises in connection with the meter accuracy. *Inaccurate readings result because circuit operation has been changed and not because the meter is registering incorrectly.*

d. SCALE. Most moving-coil meters used for d-c measurements have a linear scale with equal spaces between numbers, similar to the one shown in figure 12. The amount of deflection is directly proportional to the amount of current through the coil, and when the rated current flows through the meter the pointer deflection is full scale. When half the rated current flows through the coil, the pointer deflection is half-scale, and so on. For example, point A on the scale corresponds to a reading of 1.2, point B reads 6.5, and point C, 8.8. Nonlinear scales are discussed later in this text.

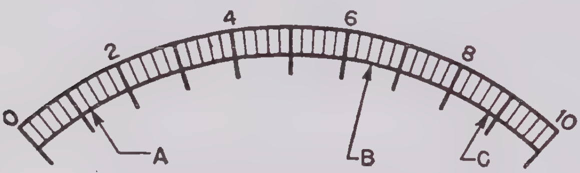


Figure 12. Linear scale used in moving-coil meters for d-c measurements.

9. Extending Range of Meter Movements

a. In radio or electrical work the meter must be capable of measuring d-c voltages ranging from a fraction of a volt to 500 volts or higher. Direct-current measurements ranging from a fraction of a milliampere to 1 ampere or more and several ranges of resistance measurement are necessary. Unless individual meters for each range are to be used, some provision must be made to modify the meter circuits so that only one meter is necessary.

b. Attempting to measure currents higher than the sensitivity rating of the meter movement being used causes too much current to flow through the meter, with resultant damage. Since there is too much current through the coil, the needle turns past full-scale deflection, hitting the right retarding pin, and this current overload can result in a bent needle, a burnt coil, or both. For example, assume that a 1-ma meter movement with an internal resistance of 27 ohms is placed across 1 volt. Only 1 ma is necessary to cause the needle to make a full-scale deflection. According to Ohm's law, the current flow through this movement when placed across 1 volt would be:

$$I = \frac{E}{R} = \frac{1}{27} = .037 \text{ ampere or } 37 \text{ ma.}$$

A current of 37 ma is flowing through a meter movement which is designed to deflect full scale when 1 ma passes through it.

c. The external circuit of the meter must be modified before it can be used to measure the range of voltages and currents found in radio and electrical circuits. To use the movement as a voltmeter, a high resistance (multiplier resistor) is added in series with the meter movement. This reduces the current to an amount the meter can handle safely, even though it is placed across a high voltage. To use the movement as an ammeter, a low resistance is placed in parallel with the movement to provide another path for the current. Part of the current flow in the circuit is bypassed by the parallel resistor, and a small portion of the circuit current flows through the meter movement. This small current can be handled without injury to the meter.

d. The rules, then, for modifying the external meter circuit are:

(1) For use as a voltmeter, place a high resistance in series with the meter movement.

(2) For use as an ammeter, place a low resistance in shunt (parallel) with the meter.

10. Basic Voltmeter

a. FINDING MULTIPLIER RESISTORS BY OHM'S LAW.

(1) To find the series resistance necessary to measure any given voltage, the full-

scale deflection, internal resistance of the meter, and voltage range to be measured must be known. The necessary series resistor then can be determined by Ohm's law. For example, it is desired to use a 1-ma movement with 27 ohms internal resistance to measure 10 volts at full-scale deflection (fig. 13). The maximum current permissible through the movement is 1 ma. Since the voltage (10 volts) and the current (1 ma) are known, the total meter-circuit resistance must be:

$$R = \frac{E}{I} = \frac{10}{.001} = 10{,}000 \text{ ohms.}$$

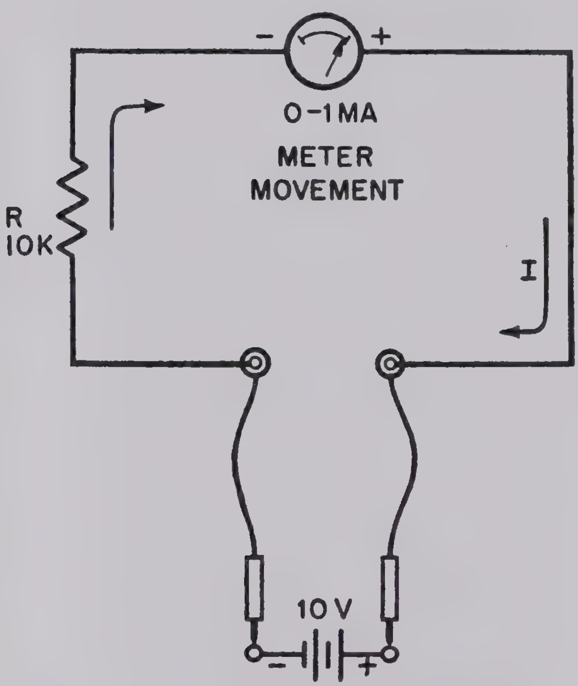


Figure 13. Series R limits current through meter movement when used as voltmeter.

(2) When the series resistance is very large compared with the internal resistance, the internal resistance need not be deducted from the value of series resistance required. In a circuit where the applied voltage is 10 volts, and a resistance of 10,000 ohms is placed in series with the meter movement, 1 ma will flow through the circuit, and the needle will swing to maximum. The voltmeter, therefore, can measure 10 volts without damage if it has a resistance of 10,000 ohms placed in series with it. The series resistance is known as a multiplier, since it extends the voltage range of the meter.

(3) The scale of the meter then can be calibrated in volts, with 10 volts representing full-scale deflection. If the meter is put across 5 volts, only .5 ma flows through the meter movement. Since $I = E/R = 5/10{,}000 = .0005$ ampere = .5 ma this is only half the maximum current the coil can handle. Therefore, only half as strong a magnetic field exists, and the meter will read half-scale. Midscale represents 5 volts, quarter-scale deflection represents 2.5 volts, and other readings will be proportional.

(4) By using the method described above, it is possible to extend the range of the meter movement to any desired amount. To extend the range of the meter to measure 500 volts with full-scale deflection, Ohm's law is used to find the resistance necessary to limit the current to the amount the movement can handle. Using the same 1-ma movement as previously, the series resistance needed is:

$$R = \frac{E}{I} = \frac{500}{.001} = 500{,}000 \text{ ohms.}$$

By putting 500,000 ohms in series with the movement, the meter now can be placed across 500 volts. Only 1 ma of current will flow through the meter movement, or just enough to make the needle deflect full scale.

b. FINDING MULTIPLIER RESISTANCE BY OHMS PER VOLT.

(1) Another method for calculating a multiplying resistor is based on *ohms per volt*—the alternate expression for meter sensitivity. Since current equals E/R and ohms per volt equals R/E,

the current sensitivity in ohms per volt is:

$$\text{Ohms per volt sensitivity} = \frac{1}{\text{current sensitivity}}$$

For example, a given meter movement has a current sensitivity of 1 ma. This means that 1 ma of current makes the needle deflect full scale. It is desired to have the meter measure 10 volts full scale. Current sensitivity can be translated into *ohms per volt* by calculating the amount of resistance that must be placed in series with the meter to measure 1 volt.

(2) To measure 1 volt, the resistance required in series with this 1-ma meter movement is:

$$R = \frac{E}{I} = \frac{1}{.001} = 1{,}000 \text{ ohms.}$$

To measure 1 volt with full-scale deflection, 1,000 ohms must be placed in series with the movement. To measure 10 volts at full scale, it is necessary to put 10 times 1,000 or 10,000 ohms in series with the movement. Therefore, a 1-ma movement can be called a 1,000-ohms-per-volt movement. It is usual to find meter-movement sensitivity expressed in ohms per volt, since it is easier to determine what multiplier resistance is necessary for any desired range.

(3) If it is desired to extend the range of a 5,000-ohms-per-volt movement with an internal resistance of 75 ohms to 300 volts, the ohms-per-volt sensitivity need only be multiplied by 300 volts:

$$300 \times 5{,}000 = 1{,}500{,}000 \text{ or } 1.5 \text{ megohm.}$$

The internal resistance can be ignored for all practical purposes.

(4) The ohms-per-volt rating is another way of expressing meter sensitivity. The less current required for full-scale deflection, the more resistance must be placed in series with the movement to measure each volt and, therefore, the greater the sensitivity. When the ohms-per-volt rating is given, it is necessary only to multiply this figure by the desired range in volts to get the required value of multiplier resistance.

12. Multirange Voltmeters

a. SEPARATE MULTIPLIERS. It is possible to have a voltmeter (fig. 14) with several ranges, by using either a switching arrangement, as in A and C, or separate pin jacks for each range, as in B and D. For example, it is desired to have a switching arrangement with four ranges and separate multipliers, using a 2-ma, 18-ohm meter movement. The ranges required are 5 volts, 50 volts, 250 volts, and 500 volts (A, fig. 14). The first step is to convert the current sensitivity into ohms per volt: Ohms-per-volt sensitivity $= \frac{1}{\text{current sensitivity}} = 1/.002 =$ 500 ohms per volt. The multiplier resistor R_1 for the 5-volt range is, therefore, 5 times 500, or 2,500 ohms. R_2 for the 50-volt range is 50 times 500, or 25,000 ohms. R_3 for the 250-volt range is 250 times 500, or 125,000 ohms. R_4 for the 500-volt range is 500 times 500, or 250,000 ohms. Resistors R_1, R_2, R_3, and R_4 are connected to the switch as shown in A and any of the four ranges can be selected by setting the switch to the voltage range desired. In B, the resistors are connected to pin jacks instead of a switch. The common or negative lead is placed in the negative pin jack and the other lead is placed in the positive pin jack of the voltage range desired.

b. SERIES MULTIPLIERS.

(1) D of figure 14 shows a series-multiplier arrangement using pin jacks. One test lead is inserted in the common pin jack (negative terminal) on all ranges. The other test lead is inserted in the pin jack for the desired voltage range. Since this is a series-multiplier arrangement, it is necessary to compute the value of the multiplier resistance for the lowest range first, or R_1. Then the total multiplier resistance for the next higher range is found. R_1 then is subtracted from this figure, and the remainder is the value of R_2. For example, it is desired to have a voltmeter with five ranges using a .5-ma or 500-microampere, 55-

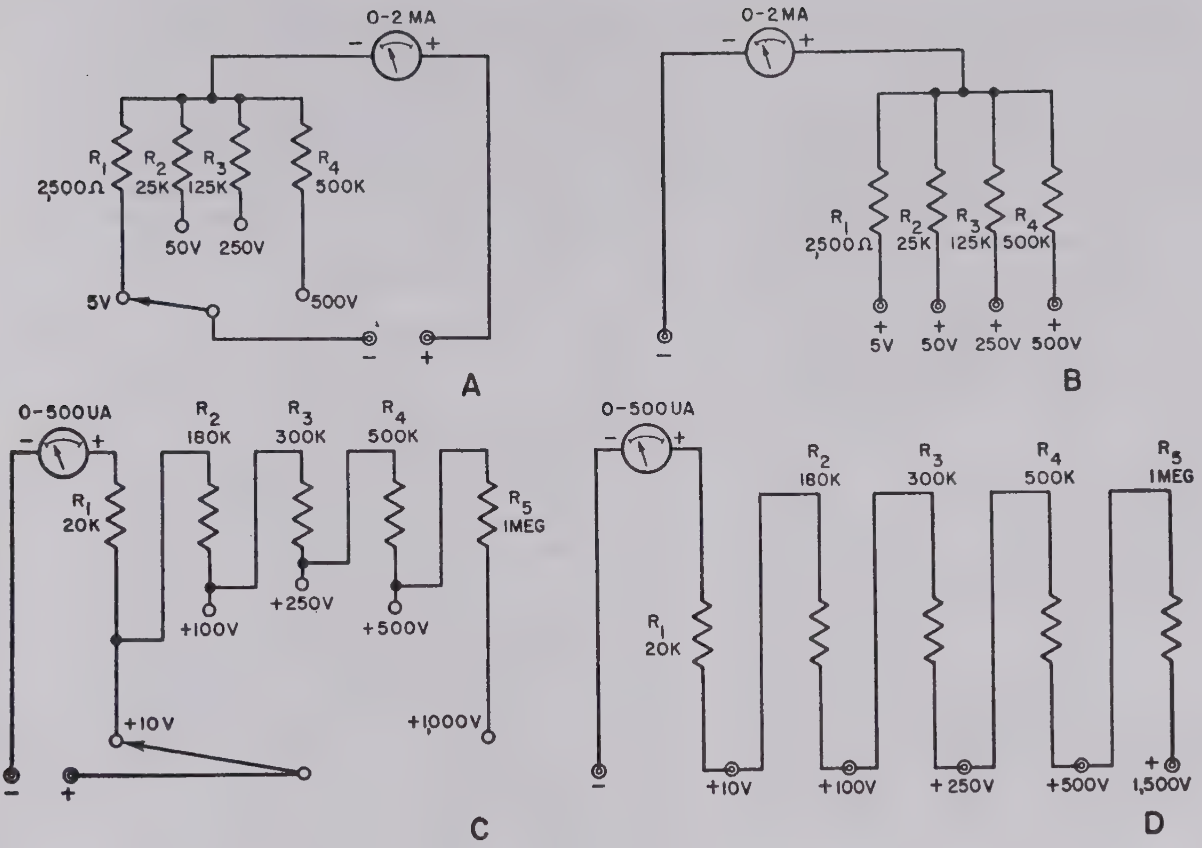


Figure 14. Different types of multirange voltmeters.

ohm movement. Ranges are to be 10, 100, 250, 500, and 1,500 volts. Since the current sensitivity is .5 ma, the ohms-per-volt sensitivity is 1/.0005, or 2,000 ohms per volt. R_1, the multiplier for the 10-volt range, is 2,000 times 10, or 20,000 ohms.

(2) For the 100-volt range, a resistor of 100 times 2,000, or 200,000 ohms, is necessary. However, in this type of meter, the second multiplier, R_2, is in series with R_1. Since the 20,000-ohm resistor, R_1, is in series with meter, R_2 will be equal to 200,000 minus 20,000, or 180,000 ohms. When the test lead is in the 100-volt pin jack, a total of 200,000 ohms is in series with the meter movement, which is the multiplier necessary for this range. The 200,000-ohm multiplier is made up of R_1 (20,000 ohms) and R_2 (180,000 ohms).

(3) For the 250-volt range, the multiplier resistance necessary is 250 times 2,000, or 500,000 ohms. R_1 and R_2 already provide 200,000 ohms; therefore R_3 need provide only the difference between 500,000 and 200,000, or 300,000 ohms.

(4) For the 500-volt range, the multiplier resistance is 500 times 2,000, or 1,000,000 ohms. Since R_1, R_2, and R_3 already provide 500,000 ohms in series, R_4 must provide the difference between 1,000,000 and 500,000, or 500,000 ohms.

(5) In the same way, for the 1,500-volt range, there must be 1,500 times 2,000 or 3,000,000 ohms. Since 1,000,000 ohms are already in series, R_5 need

provide only the additional resistance. This is 3,000,000 minus 1,000,000, or 2,000,000 ohms.

c. TYPES OF MULTIPLIERS. Resistors used as multipliers can be either the carbon or the wire-wound type. The more expensive meters use precision wire-wound resistors with a tolerance of .1 percent. The carbon resistor also can be used as a multiplier if its value is within tolerance limits. This resistor is found in the cheaper instruments where a precise reading is not necessary and an approximate reading can be tolerated. It may serve also as an emergency replacement to keep needed test equipment in service.

13. Basic Ammeter

a. FUNCTION OF SHUNTS. To measure current, the circuit under test is broken and an ammeter is inserted in the break. When the meter is in series with the other circuit components, and the full circuit current to be measured is more than the meter movement can handle, a shunt or small resistor can be inserted in parallel with the movement, to divert the excess current around the movement (A, fig. 15). The basic meter movement generally is a microammeter or a milliammeter, and the range is extended by using a shunt.

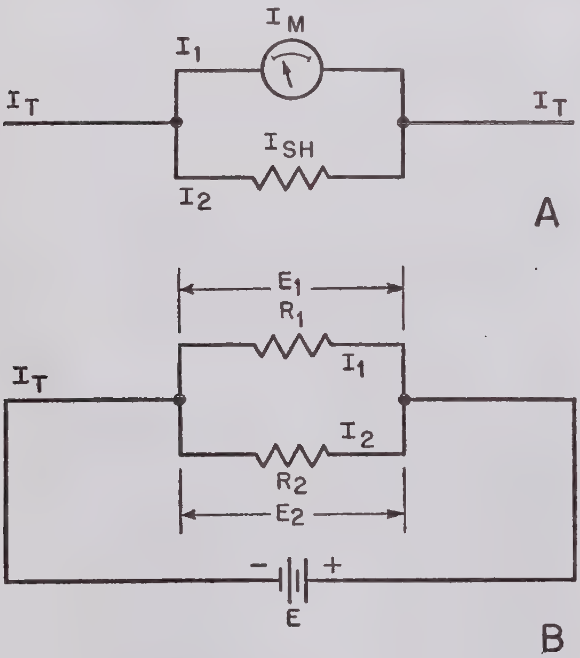


Figure 15. Current flow in a parallel circuit.

b. CURRENT THROUGH RESISTORS IN PARALLEL. In a circuit consisting of two resistors in parallel, current divides, and more current flows through the smaller resistor than through the larger one. If two resistors, R_1 and R_2, are in parallel, the voltages across both are equal, or E_1 is equal to E_2 (B, fig. 15).

Also $E_1 = I_1 \times R_1$

and $E_2 = I_2 \times R_2$.

Since $E_1 = E_2$, then $I_1R_1 = I_2R_2$.

Transposing, $\frac{I_1}{I_2} = \frac{R_2}{R_1}$.

This equation states that in a parallel circuit containing two resistors the current in each resistor is inversely proportional to its resistance. If one resistor is twice the size of the other, the current flowing through the larger resistor is one-half the current in the smaller resistor. If one resistor is three times larger than the other, only one-third of the current will flow through it. This is true because Ohm's law states that I times R must equal the same voltage when the resistors are in parallel.

c. SHUNT FORMULA.

(1) The two circuits in figure 15 show the similarity between a parallel circuit containing two resistors and a meter-and-shunt combination. The formula given in the previous paragraph can be transposed to:

$$R_1 = \frac{R_M I_2}{I_1}$$

and, since the circuits are similar, the circuit in A can be expressed:

$$R_{SH} = \frac{R_M I_M}{I_{SH}}$$

where R_{SH} is the shunt resistance, R_M the meter-movement resistance, I_M the meter-movement current for full-scale deflection (current sensitivity), and I_{SH} the shunt current. The formula now can be used to calculate the values of shunts for meter movements.

(2) It is desired to extend the current range of a 1-ma, 27-ohm movement to 10 ma. This means that a current of

10 ma will be flowing in the circuit when the needle is fully deflected (fig. 16). Since the movement can handle only 1 ma at full-scale deflection, the shunt resistance must handle the balance of the current, or 9 ma. To compute the shunt resistance necessary, the formula for R_{SH} is used.

$$R_{SH} = \frac{R_M I_M}{I_{SH}} = \frac{27 \times .001}{.009} = 3 \text{ ohms.}$$

The figure used for I_{SH} is the actual current that will flow through the shunt, which is 9 ma (total current minus meter-movement current) and not the total current (10 ma). Since the shunt is one-ninth the value of the meter resistance, there will be nine times as much current flowing through it. If the meter is connected in a circuit carrying 5 ma of current, this current will divide in a ratio of one to nine between meter movement and shunt. The current flow through the shunt will be 4.5 ma, the current flow through the meter movement will be .5 ma, and the meter needle will deflect half-scale. Since full scale represents 10 ma, then half-scale deflection represents a current of 5 ma, and all currents between 0 and 10 ma will read in proportion.

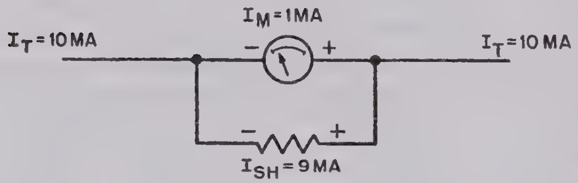


Figure 16. Extending a 1-ma movement to measure 10 ma.

(3) The internal resistance of the movement must be considered in finding the value of shunt resistance, since the value of parallel resistance depends on the value of meter-movement resistance. It is possible to ignore internal resistance only when constructing voltmeters, since large values of resistance are put in *series* with the movement, and internal resistance is negligible as compared with the multiplier resistance.

d. TYPES OF SHUNTS. In radio work, the currents measured generally are small, and meters have internal shunts. These shunts can be made of copper, nichrome, or any low-resistance conductor. Whenever the current to be measured is more than 30 amperes, the shunt usually is located outside the meter to prevent injury to the movement by heat generated in the shunt by the high current. Copper and manganin blocks are used for these low-resistance shunts, since they have a low-temperature coefficient and are capable of carrying extremely high currents. The resistance of these high current shunts is very low (much less than 1 ohm); the leads connecting it become part of the total shunt resistance, and any change in the length of the leads affects the accuracy of the readings.

14. Multirange Ammeter

a. MULTIPLE SHUNTS. In the multirange ammeter, it is possible to have several ranges of measurement. The meter can have a switching arrangement to change from one range to another (fig. 17), or pin jacks may be used. For example, it is desired to extend the range of a basic 0- to 10-ma ammeter to permit measurements from 0 to 10 ma, 0 to 100 ma, 0 to 1 ampere, and 0 to 10 amperes. For range 1 (0 to 10 ma), no shunt is necessary, since the movement is designed to handle 10 ma. For range 2 (0 to 100 ma), R_{SH} equals $R_M I_M / I_{SH}$ or 9 times .01/.09, or 1 ohm. For range 3 (0 to 1 ampere), R_{SH} is equal to 9 times .01/.99, or .091 ohm. For range

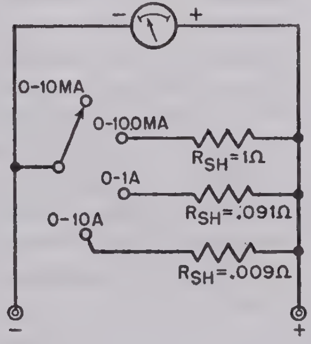


Figure 17. Multirange ammeter using separate shunts and switch.

4, 10 amperes is used to compute the shunt instead of the actual current of 9.99 amperes, because there is practically no numerical difference in the answer using either figure.

b. Ring Shunts.

(1) Many commercial milliammeters use a tapped or ring shunt in place of separate shunts. In this arrangement, some of the resistance may be in series with the meter movement and some in parallel, depending on the range (fig. 18). For example, on the lowest range, 0 to 15 ma, all of the shunt resistors, R_1, R_2, and R_3 are in parallel with the movement, as in A. On the next range, 0 to 50 ma, R_3 is in series with the movement and R_1 and R_2 are in parallel with the movement, as in B. On the highest range, 0 to 100 ma, R_2 and R_3 are in series with the movement, and R_1 is in parallel with the movement, R_2, and R_3, as in C. Ring shunts have an advantage over separate shunts, since part of the total resistance is placed in series with the movement; therefore the parallel resistors do not have to be as low in value.

(2) To compute the values of ring shunts, the mathematical relationship between parallel resistors and current must be understood. In figure 19, R_A is 30 ohms, R_B is 60 ohms, and they are in parallel. If a total current of 3 ma is flowing in the circuit, 30/90 or one-third of the current will flow through the 60-ohm resistor (higher value in ohms) and 60/90 or two-thirds of the current will flow through the 30-ohm resistor (lower value in ohms). The current of 2 ma in the smaller resistor, R_A, is twice the amount of current flowing in R_B. There is the same ratio between one branch current and total current as there is between the opposite branch resistance and the sum of the two branch resistances (R_T). That is,

$$\frac{I_A}{I_T} = \frac{R_B}{R_T}$$

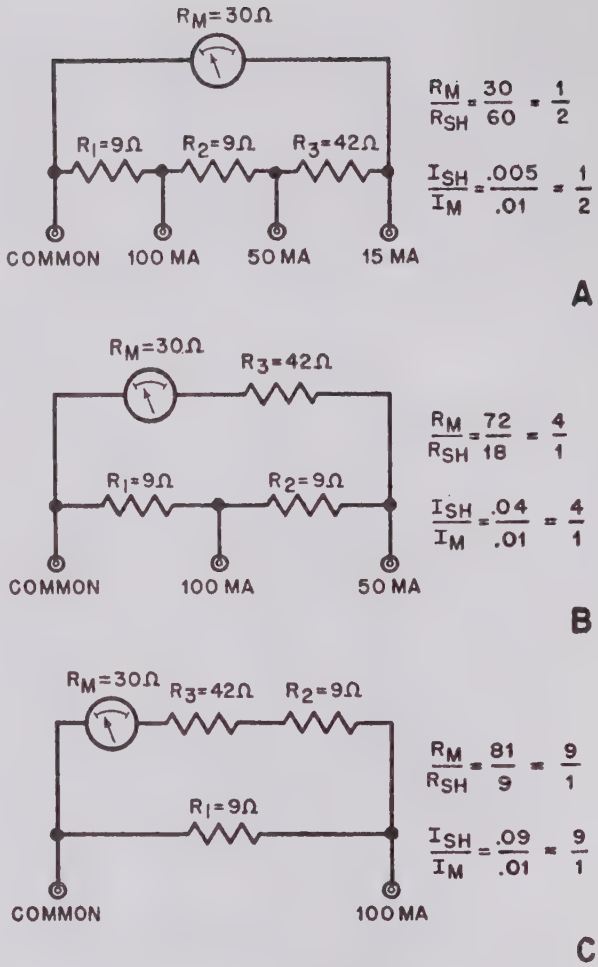


Figure 18. Ring shunt ammeter.

Where R_T is R_A plus R_B, and I_T is I_A plus I_B. This can be seen by substituting values in the equation.

$$\frac{I_A}{I_T} = \frac{R_B}{R_T} = \frac{2}{3} = \frac{60}{90}.$$

(3) Multiplying both sides by R_T, the formula becomes:

$$R_B = \frac{R_T I_A}{I_T}.$$

To use this formula for a meter shunt circuit, assume that the two parallel resistors represent a movement and a shunt resistor. Subletter *A* becomes *M* and subletter *B* becomes *SH*. The formula is then:

$$R_{SH} = \frac{R_T I_M}{I_T}.$$

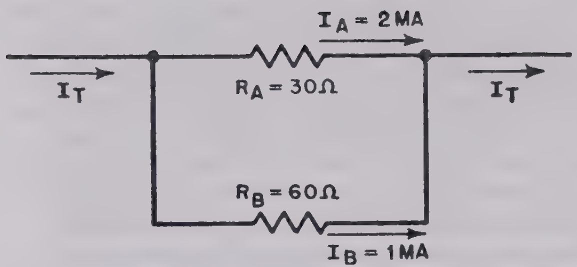


Figure 19. Computing resistance and current for a parallel circuit.

(4) To solve ring shunt problems, the value of the entire shunt resistance is found by the shunt formula R_{SH} equals $I_M R_M / I_{SH}$, and the individual shunt values in the ring are found by using the formula R_{SH} equals $R_T I_M / I_T$.

(5) For example, find the value of each resistor in the ring shunt of figure 18. The meter has a 10-ma, 30-ohm movement. First, it is necessary to find the value of the whole shunt, or R_1 plus R_2 plus R_3. On the 15-ma scale, all the resistors are in series (R_1 plus R_2 plus R_3) and act as a shunt to the meter movement. Using the old shunt formula,

$$R_{SH} = \frac{I_M R_M}{I_{SH}} = \frac{.01 \times 30}{.005} = 60 \text{ ohms.}$$

Therefore, R_1 plus R_2 plus R_3 is equal to 60 ohms. Now that the entire shunt value is known, it is possible to find R_T by computing the value of the individual resistors in the ring shunt. It should be remembered that R_T means the sum of the entire shunt plus the internal resistance of the movement. Since the entire shunt is 60 ohms and the internal resistance of the movement is 30 ohms, R_T is equal to 90 ohms. The value of the shunt for the highest range (0 to 100 ma), can now be computed. For this range, as in C, R_1 acts as the shunt. Using the ring-shunt formula,

$$R_1 = \frac{R_T I_M}{I_T} = \frac{90 \times .01}{.1} = 9 \text{ ohms.}$$

For the 50-ma range, the shunt is R_1 plus R_2, as in B, and

$$R_1 + R_2 = \frac{R_T I_M}{I_T} = \frac{90 \times .01}{.05} = 18 \text{ ohms.}$$

Since R_1 is 9 ohms and R_1 plus R_2 is 18 ohms, it is obvious that R_2 must be 9 ohms. Then, R_3 must be the difference between 60 ohms and 18 ohms, or 42 ohms.

15. High-Resistance Meter

a. When a low-resistance voltmeter is used to measure the voltage across a high value of resistance, circuit conditions may be upset and cause inaccurate readings. For example, in A of figure 20, two 100,000-ohm resistors are in series across a 60-volt battery. Since the resistances are equal, there must be 30 volts across each one.

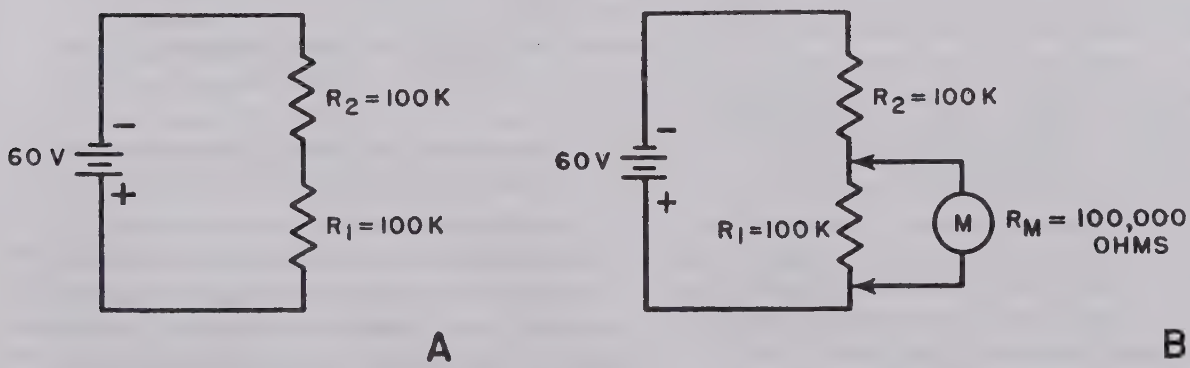


Figure 20. Low-resistance meters in high-resistance circuits give inaccurate voltage readings.

b. Suppose a 1,000-ohms-per-volt meter is placed across R_1, with the meter on the 100-volt scale, as in B. Then 100,000 ohms of resistance are in series with the meter (1,000 ohms per volt times 100 volts). When the meter is placed across R_1, two 100,000-ohm resistors are in parallel and the combined value becomes equal to 50,000 ohms. As a result of this change in resistance, the voltage distribution in the circuit changes. The total circuit resistance is now 150,000 ohms instead of 200,000 ohms. Because R_2 now has two-thirds of the total resistance in the series circuit, 40 volts, or two-thirds of the total voltage, appears across R_2, and only 20 volts appears across the combination of R_1 and the meter. The meter always reads the voltage across itself, and this is 20 volts, but as soon as it is removed, the voltage across R_1 changes back to 30 volts. *Placing a comparatively low-resistance voltmeter in the circuit may upset circuit conditions, leading to inaccurate readings.*

c. When a more sensitive meter with a higher value of multiplier resistance is used, the reading is more accurate. A 20,000-ohms-per-volt meter on the 100-volt range has 2,000,000 ohms of resistance in series with the meter movement (20,000 ohms per volt times 100 volts is equal to 2,000,000 ohms). When a 2,000,000-ohm resistor is placed in parallel with the 100,000 ohms of R_1, the combined parallel value of resistance remains 100,000 for all practical purposes. Therefore, no voltage redistribution takes place when the meter is connected across R_1, the voltage remains 30 volts, and the meter reads accordingly.

d. The higher the sensitivity of the movement, the more multiplier resistance it has for a given range, and consequently, the less it can upset circuit conditions when voltages are measured. When only a low-resistance meter is available to take voltage readings in high-resistance circuits, the shunting effect of the meter must be accounted for. The shunting effect can be reduced by taking a reading on the highest practical range of the meter, even though the deflection obtained is not great. The added resistance of the meter causes less redistribution of voltage and reduces the inaccuracy of the reading.

16. Meter Applications

a. Another method for measuring voltages higher than the meter can handle is to build a voltage divider with 10 resistors of the same value in series. The values of these resistors should be at least 1 megohm so that little current is drawn from the load. This divider then is connected across the voltage to be measured, and a reading is taken across one resistor of the divider. The total voltage is 10 times the actual reading of the meter, because the 10 resistors are equal in value and the meter measures one-tenth of the entire value.

b. Unlike the voltmeter, the ammeter should have low resistance to prevent changing circuit operation. If an ammeter is inserted in a circuit where the total resistance is small, it reduces the current flow appreciably. When the ammeter resistance is small in comparison with the series resistance in the circuit, however, it has a negligible effect on the total current, and the meter reading is accurate. In trouble shooting, the technician seldom takes current readings, since this involves opening a circuit. Sufficient information usually can be obtained by taking voltage and resistance readings to find the source of trouble. When necessary, the current may be computed by measuring the voltage and resistance, using Ohm's law to find the current. If a current reading is desired, and a suitable ammeter is not available to make the reading, usually it is simpler to find the current by the voltage method than to make a shunt of the required value. Connect a small resistor of known value in series with the circuit and measure the *voltage* across the resistor. Then compute the current by Ohm's law. The resistance inserted in the circuit must be small (less than one-tenth of the series resistance in the circuit), or inaccurate readings result.

17. Precautions in Using Voltmeter and Ammeter

a. Since an ammeter has a low resistance, it is important to be especially careful in using it. If mistakenly put across a voltage source, the meter can be damaged. Never connect an ammeter or milliammeter *across* a battery or resistor. Always break the circuit and connect

the meter in *series,* one meter lead going to each point of the circuit break.

b. Connect voltmeters in parallel or across the circuit component being measured.

c. When using either ammeters or voltmeters:

(1) Always start at the highest meter range when measuring an unknown quantity. Then drop down to a lower range if necessary. This practice protects the meter from injury which may result if an attempt is made to read a high value in a low range.

(2) *Observe polarity.* Test leads usually are color-coded—black for negative and red for positive. Place them in their proper pin jacks.

18. Summary

a. The moving-coil meter is popular in radio and electrical work because it is accurate, rugged, and has a linear scale.

b. The main parts of the moving-coil meter are:

(1) A strong horseshoe permanent magnet with soft-iron pole pieces.

(2) A circular air gap which produces a uniform radial magnetic field.

(3) A coil wound on a rectangular aluminum frame with indicating needle attached.

(4) Hard-steel pivots in jeweled bearings supporting the coil assembly.

(5) Two light, spiral springs, oppositely wound, to compensate for temperature changes.

(6) An adjusting screw for zero-adjust of the meter.

(7) A very light moving-coil assembly, since very small currents are required for full-scale deflection.

c. Three systems are involved in the operation of a meter: motor, control, damping.

d. The motor system of moving-coil meters depends on the current flowing through a coil and magnetizing it. The coil then is repelled by a permanent magnet in proportion to the amount of current passing through the coil.

e. A control system consists of two oppositely wound springs that control the amount of deflection, bring the coil back to 0, conduct current to and from the coil, and compensate for temperature changes.

f. A damping system brakes the pointer swing. This is accomplished by:

(1) Eddy currents in the aluminum frame setting up an opposing field as the coil moves.

(2) A counter emf in self-supporting coils which are used only as ammeters.

g. The accuracy of the meter movement is expressed in percentage of full-scale deflection.

h. The internal resistance of a meter is the amount of d-c resistance in the coil assembly.

i. Sensitivity of meter movements can be expressed in two ways: In amount of current needed for full-scale deflection, and in ohms per volt—that is, the number of ohms which must be put in series with the meter to measure 1 volt.

j. Meter movements can measure only small currents directly. Their circuits can be modified to measure a large range of voltages or currents. To use a movement as a voltmeter, a large resistance is placed in series with it. To use it as an ammeter, a small resistance is placed in parallel with it.

k. The high values of resistance in high-resistance voltmeters (meters with high sensitivity) upset circuit conditions less, and therefore, give more accurate voltage readings in radio circuits.

l. The following precautions are necessary in using meters:

(1) Never connect an ammeter across a battery or a resistor; always connect it in series with them. The circuit must be broken to connect an ammeter in it.

(2) Connect voltmeters in parallel with the component to be measured.

(3) For both types of meters, observe polarity. Start with the highest range, and go down, if necessary, to get a readable scale deflection.

19. Review Questions

a. Draw a simplified drawing of a moving-coil meter and label the important parts.

b. With reference to the moving-coil meter, define and describe the motor system, the control system, and the damping system.

c. Explain what is meant when a meter is said to be accurate within 2 percent.

d. Define: (a) sensitivity of a meter movement, (b) internal resistance of a meter.

e. Can an unmodified moving-coil movement be used in general radio work? Explain.

f. Using a 500-μa, 55-ohm movement, compute the resistor values of a 5-range voltmeter, using the following ranges: 5 volts, 50 volts, 125 volts, 500 volts, and 1,000 volts.

g. Compute the resistor values of a 4-range voltmeter with a 5-ma, 12-ohm movement. Ranges: 10 volts, 100 volts, 250 volts, and 500 volts.

h. Using a 2-ma, 18-ohm movement, compute the resistor values of a 4-range ammeter using separate shunts. Ranges: 2 ma, 10 ma, 100 ma, and 1 ampere.

i. A ring-shunt milliammeter is to be constructed, using a 1-ma, 27-ohm movement. Ranges: 1.5 ma, 10 ma, and 20 ma. Find the resistor values.

j. What is the effect of using low-resistance voltmeters across high-resistance circuits? Explain.

k. Outline precautions to be observed when using d-c meters.

III. A-C AMMETERS AND VOLTMETERS

20. Low-Frequency A-C Meters

Three types of meters are used widely for measuring low-frequency ac: The repulsion-type moving vane, which measures either ac or dc, but is relatively insensitive; the copper-oxide rectifier, which changes the ac to dc and then measures the rectified dc on a sensitive meter suitable for measuring dc only; and the vtvm, which uses vacuum tubes to amplify the a-c voltage and then measures the change in d-c current produced in the plate circuit of the vacuum tube by the a-c voltage being measured. Before discussing these meters in succeeding paragraphs, a brief review of some a-c definitions is offered as an aid to the understanding of how ac is measured.

a. NATURE OF AC. Alternating current flows periodically first in one direction and then in the opposite direction, as shown in figure 21. The time necessary for the current to go from 0 to a maximum positive, to 0, to maximum negative, and return again to 0 is the time for 1 cycle. That portion of the cycle during which the current flow is in one direction only, as in B, is called an alternation. Frequency is the number of cycles occurring per second and an alternating current may be any frequency.

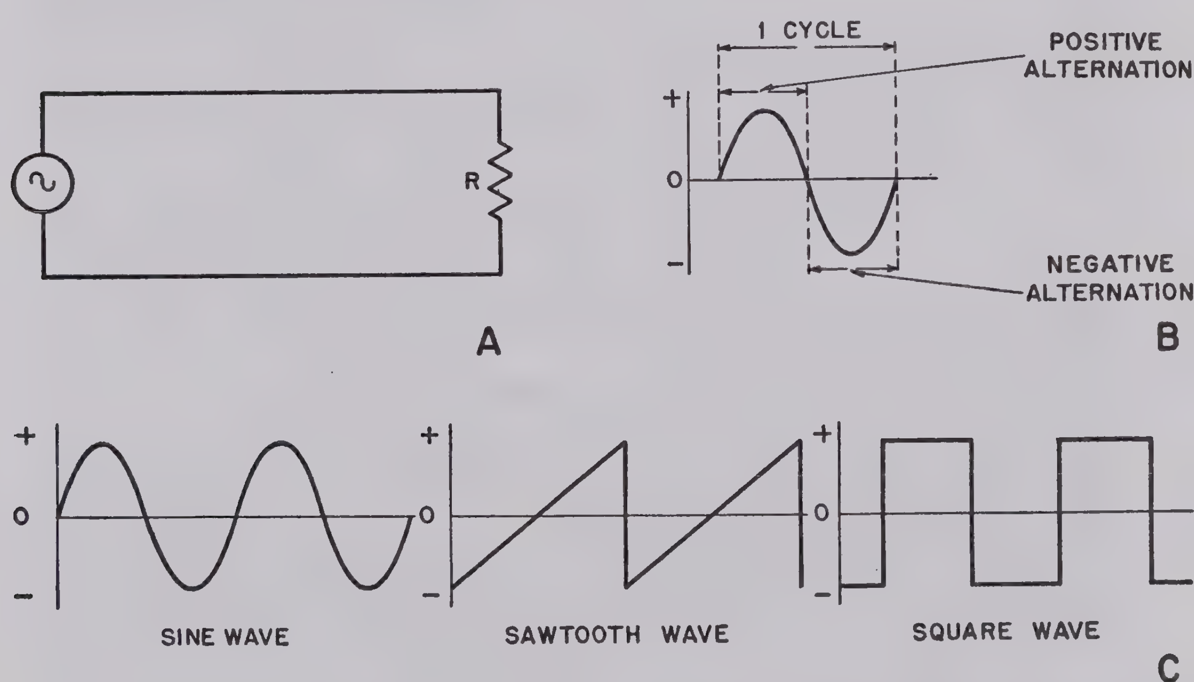


Figure 21. Fundamental a-c ideas.

b. WAVESHAPE. The waveshape is a graphical picture of current or voltage, varying in relation to time. The graphs in C show instantaneous values of amplitude and direction at any instant. Sine waves, square waves, and sawtooth waves are a few of the many forms an a-c wave may take.

c. RMS VALUE OF SINE WAVE.

(1) The mathematical average of an a-c sine-wave cycle is 0, since the positive and negative halves of the cycle are equal. The words *positive* and *negative* are convenient labels to indicate that the current changes direction, but, from the standpoint of circuit operation, current flows during both halves of the a-c cycle and accomplishes as much work in one direction as in the other. When current follows a sine-wave pattern, its amplitude is changing constantly during each alternation and the problem in measuring ac is this: The fundamental electrical units, the volt and the ampere, are based on dc. How do the constantly changing values of voltage and current in a sine wave compare with dc? It cannot be the peak value, for example, since the sine wave reaches the peak value for only an instant during each alternation.

(2) To obtain a relationship between ac and dc, the heating effects of both were studied. It was found that a current or voltage equal to .707 of the peak a-c amplitude produced in a given value of resistance the same heating effect as an equal amount of dc. For example, a circuit has sine waves of ac with a peak value of 5 amperes flowing through it. This current has a heating effect equal to .707 of 5, or 3.535 amperes of dc, and is called the *rms* (root mean square) or *effective* value:

$$I_{eff} = .707\ I_{max}$$

$$I_{max} = \frac{I_{eff}}{.707} = 1.414\ I_{eff}.$$

(3) The heating effect of current is based on the power formula, P equals I^2R, which determines the power dissipated in the form of heat. This heat varies as the square of the current, and when the sine wave reaches its peak value, the heat becomes maximum (the peak value of current squared times the resistance). To find the amount of heat dissipated in the circuit during the entire sine-wave cycle, each instantaneous value of current is squared, and a mean, or average, of the sum of these values is found, and the square root taken. The value obtained is the effective or rms value and corresponds to .707 of the peak value.

d. A-C METERS CALIBRATED IN RMS. A-c meters are calibrated so that they read the rms value of the sine wave of voltage or current being measured. When an a-c meter reads 70.7 ma, for example, a sine wave of current with a peak value of 100 ma is being measured.

e. AVERAGE VALUE AND FORM FACTOR. Two other values of the sine wave are important in understanding how meters are calibrated: The average of the instantaneous values of current during one alternation is taken, and it is found that

$$E_{ave} = .637\ E_{max}.$$

The effective value is, therefore, larger than the average value by

$$E_{eff}/E_{ave} = .707/.637 = 1.11.$$

The factor 1.11 is known as the *form factor* for a sine wave, and is the ratio of the effective voltage to the average voltage. The effective and average values given apply *only to sine waves* of current and voltage.

21. Moving-Vane Meters

The only moving-iron meters used today are of the moving-vane type. Although these meters measure either ac or dc, they usually are used exclusively for a-c measurements because more sensitive and more accurate instruments are available for dc. However, moving-vane meters can be used for measuring low-frequency voltages and current.

a. BASIC MOTOR SYSTEM.

(1) *Repulsion of iron vanes.* The motor system of moving-vane meters is based on the principle that two soft-iron

vanes repel each other when magnetized with the same polarity (fig. 4). The vanes are placed inside a coil, and the coil becomes an electromagnet when current is allowed to flow. Lines of force leave the north pole of the coil, bend around the outside in all directions, and re-enter the coil at the south pole. Within the coil, many lines of force pass through the iron vanes, since the iron has a lower reluctance than the air. As a result of these lines of force going through the iron vanes, flux lines at the top and bottom of the vanes are close together. This concentration of lines of force in the same direction causes the vanes to move away from each other. On the next alternation of current the vanes also repel each other, because the polarity of the coil reverses when the current reverses. The polarities of both vanes reverse at the same time and, even though reversed, they still repel. The *radial-vane* and the *concentric-vane* meters use this motor system.

(2) *Radial-vane meter.* In the radial-vane meter, a rectangular iron vane is placed inside the coil. One is fixed in position; the other has a pointer attached and is free to move on its pivots (fig. 5). These pivots fit in jewelled bearings and allow the vane to turn with a minimum of friction. When current flows through the coil, the rectangular vanes become magnetized and repel each other. The moving vane swings away on its pivots, and the attached needle indicates the strength of the current passing through the coil.

(3) *Concentric-vane meter.* The concentric-vane meter differs somewhat from the radial-vane meter in construction, although it follows the same general principles of operation. The soft-iron vanes are semicircular (fig. 6) and are called concentric because one vane is inside the other. The fixed vane is outside and tapered at one edge, and the inner vane is pivoted and has square edges. When current flows through the coil, lines of force pass through both vanes. The lines of force through the movable inner vane are distributed evenly; the fixed vane has a tapered edge and the concentration of flux lines is not uniform. Fewer lines pass through the tapered point than through the rest of the vane because it has less iron and more reluctance. The crowded lines of force repel each other and the movable vane is forced to swing in the direction that will redistribute the lines until there is maximum space between them. This means that the movable vane swings in the direction in which the tapered vane is pointing, since there are fewer lines of force in that direction. The amount of swing depends on the strength of current flowing through the coil and the control action of the springs.

b. CONTROL SYSTEM. Both radial-vane and concentric-vane meters have springs to provide control action (fig. 22). The springs provide the correct amount of opposition to the swing of the movable vane. They also serve to bring the pointer back to 0 when the meter is removed from the circuit. The needle registers at the point where the repelling force of the vanes equals the counterpull of the springs.

c. DAMPING SYSTEM. In small radial-vane meters, the coil is inclosed in a metal container and the moving vane fits snugly in the space. As the moving vane is repelled, it compresses the air in front of it and its speed of travel to the indicating position is decreased. When the needle comes to a stop, there is no further damping or braking action. In larger meters, a light aluminum damping vane is attached to the same rod as the pointer and moving vane (fig. 22). The damper vane then is inclosed in a separate, air-tight damping chamber and the damping action is very efficient.

22. Additional Characteristics of Moving-Vane Meters

a. SCALE CALIBRATION.

(1) *Square-law scale.* The concentric-vane

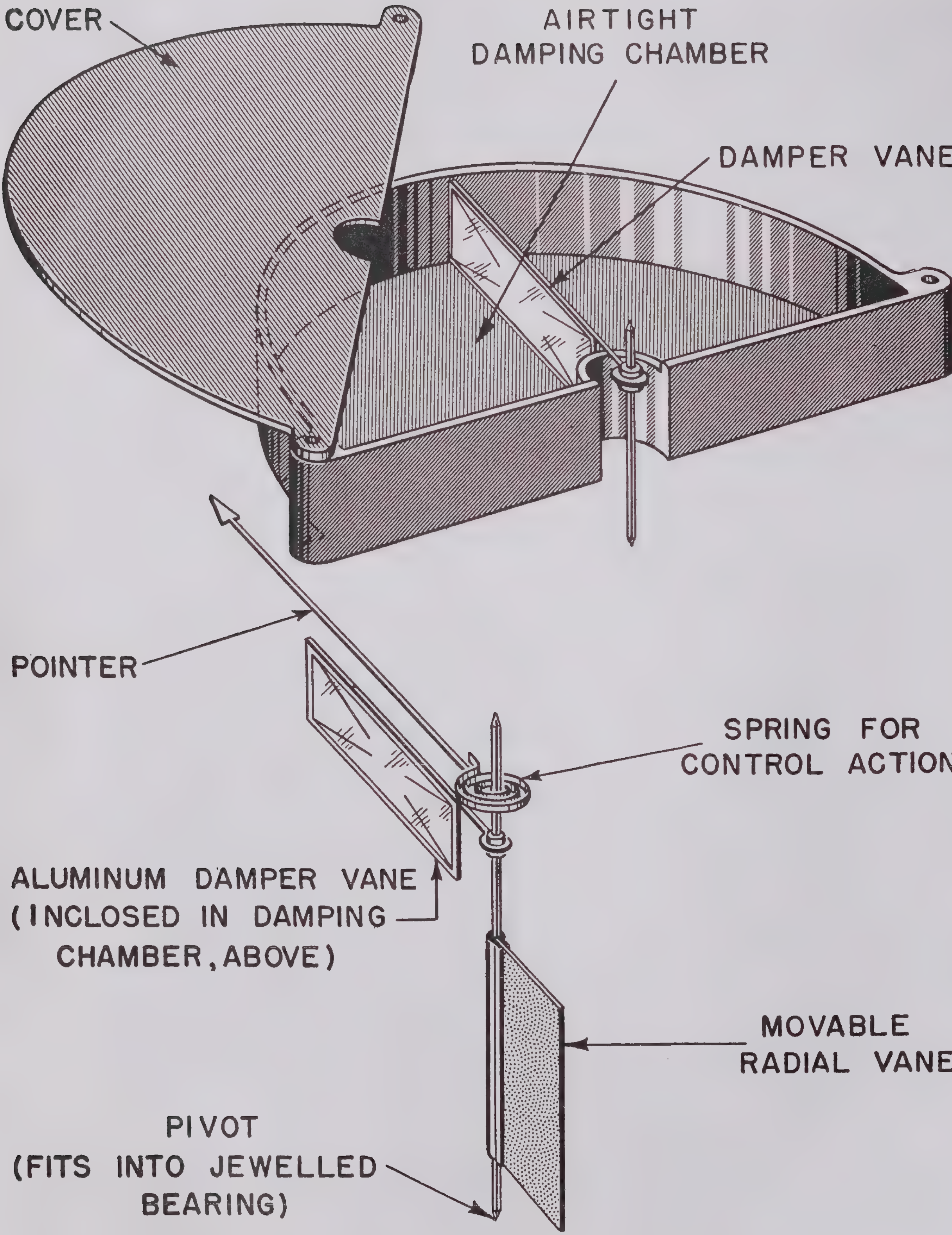


Figure 22. Air-damping system used in moving-vane meters.

causes the pointer to indicate according to the square law rather than in direct proportion to the amount of current flow. For example, if the current is doubled, the magnetic field around each vane is twice as strong. Since each vane repels twice as much, the combined repulsion of the two vanes is four times as great. The repulsion and the pointer swing *do not vary directly* with the current; they vary as the *square* of the current. Doubling the current results in four times the deflection, tripling the current results in nine times the deflection, and so on. Deflection is, therefore, said to be square law and the scale is nonlinear, with the numbers on the low end of the scale crowded together and the numbers on the high end spread farther apart. In a true square-law scale, any point on the scale which represents twice the value of a point lower on the scale also represents four times the deflection. For example, figure 23 shows full-scale deflection as 10 and quarter-scale deflection is 5. Doubling the current gives four times the deflection.

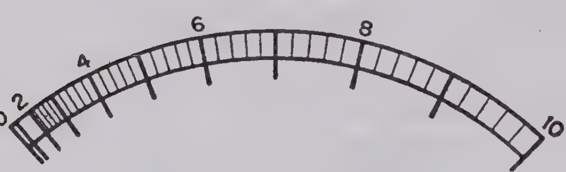


Figure 23. Square-law scale.

(2) *Calibration in rms values.*

(*a*) When a sine wave of current passes through the coil, the current is not steady but is changing constantly. If 60 cps is being measured, current through the coil goes from 0 to peak value to 0 in one direction, then does the same in the opposite direction, 60 times per second. The lines of force are continually changing in strength as well as direction. The amount of repulsion the vanes have for each other, therefore, varies from 0 to maximum to 0 120 times per second, since they repel each other on both halves of the cycle.

(*b*) The meter needle remains steady at one position because the iron vanes have so much inertia they cannot follow the instantaneous changes of flux. It is physically impossible for them to change position 120 times per second. The vanes, therefore, take a position based on the average value of lines of force present over each alternation. This depends on the average value of current, which is .637 times the peak value, and the meter needle indicates this value of current.

(*c*) To have any meaning, a-c measurements must be in terms of *rms*, or the heating equivalent of dc. For this reason, the markings on the scale are in terms of the rms value, rather than the average value, of the sine wave. For example, a scale is being designed for a new meter. A sine wave of voltage with a peak value of 100 volts is placed across the meter and the needle registers the average value, or 63.7 volts. This position of the needle then is marked with the effective value, or 70.7 volts (E_{eff} equals .707 times 100, or 70.7 volts) and the rest of the scale is calibrated in the rms rather than the average value.

(3) *Sine-wave calibration.* Most a-c meters are calibrated on the basis of a 60-cps sine wave. However, not all of the ac found in radio circuits has a sine-wave shape. *When an a-c meter is used to measure nonsinusoidal voltages and currents, an approximate indication of values is obtained and not exact information.*

b. Frequency Response. Moving-vane meters generally are not used to measure ac above 100 cps since most of them are calibrated on the basis of a 60-cps sine wave. The inductive reactance of a coil (X_L equals $2\pi fL$) increases with frequency and causes a reduction in the current flowing through it. Owing to

this increased reactance, when moving-vane meters are used to measure frequencies higher than the usual line frequency, inaccurate readings result. Core losses (hysteresis and eddy-current losses) also increase in the iron vanes at higher frequencies and introduce comparatively large power losses in the circuit being measured.

c. ACCURACY. Most moving-vane meters have a rated accuracy of plus or minus 5 percent.

d. ZERO-ADJUST. The screw in the front of the case moves the spring and permits the pointer to be adjusted to 0.

e. IRON CASE. Magnetic shielding is used to prevent outside magnetic fields from influencing the meter readings. This is accomplished by inclosing the meter in an iron case.

f. USE AS VOLTMETER AND AMMETER. For use as a voltmeter, the coils of the moving-vane meter are wound with many turns of fine wire and multiplier resistors can be used as needed to increase the range. For ammeter use, the coils have fewer turns and larger wire is used. Moving-vane meters can be used to measure fairly high currents without the use of shunts. However, because of their low sensitivity, they cannot measure small currents as well as the moving-coil meter. The highest sensitivity available is about 15 ma, which corresponds to 67 ohms per volt. Moving-vane meters are useful for measuring voltage and current at line frequencies, but because of their low sensitivity they generally are not used in circuit testing.

23. Copper-Oxide Rectifier Meter

In circuit testing, most low-frequency a-c measurements are made with either a copper-oxide rectifier meter or a vtvm. The copper-oxide rectifier meter is more sensitive and more accurate than the moving-vane meter, but not as sensitive as the vtvm. It often is a part of a multimeter, which also is used to measure direct current, d-c voltage, and resistance.

a. COPPER-OXIDE RECTIFIER CONSTRUCTION. The copper-oxide rectifier meter is a combination of a d-c moving-coil meter (d'Arsonval movement) and a copper-oxide rectifier. The ac is rectified and the pulsating dc then is measured by the d-c meter. The copper-oxide rectifier consists of several copper disks with each disk having a layer of copper-oxide on one of its sides. Lead washers separate the disks, and they are clamped together under pressure. The disks can be arranged to provide either half-wave or full-wave rectification (fig. 24).

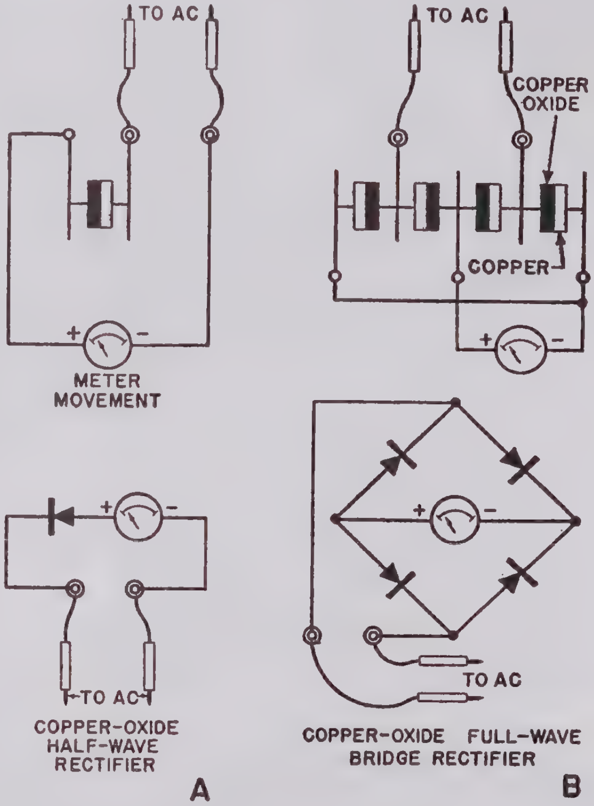


Figure 24. Copper-oxide rectifiers, half-wave and full-wave.

b. RECTIFIER ACTION. The function of a rectifier is to change ac to a form of dc. This means that the current from the output of the rectifier does not reverse its direction. It allows current to pass readily in one direction through the circuit but not in the reverse direction.

(1) *Unidirectional conduction.* The resistance to the current flow from the copper to the copper-oxide is very low compared with the resistance in the reverse direction. Because of this, the current flow is said to be unidirectional and this device can be used as a rectifier.

(2) *Half-wave rectification.* When ac is applied to a rectifier in series with a resistor (A, fig. 25), current passes through the rectifier from the arrowhead to the flat side, but not in the opposite direction. The current through the resistor is not reversing its direction and is no longer ac, but pulsating dc. In half-wave rectification, current flows through the resistor during one alternation of each cycle, but not during the other.

(3) *Full-wave rectification.* Current can be made to flow through the resistor in the same direction during both halves of the a-c cycle by using the bridge rectifier circuit shown in B of figure 25. When the positive alternation is applied to rectifier 1, current flows from the generator through rectifier 2, resistor *R from left to right,* rectifier 1, and back through the generator. On the next alternation, the polarity of the generator reverses. Current then flows from the generator through rectifier 4, resistor *R from left to right,* rectifier 3, and back through the generator. The current flows through the resistor in the same direction on both alternations. The ac from the generator becomes pulsating dc—pulsating because the current is not steady in value and dc since the

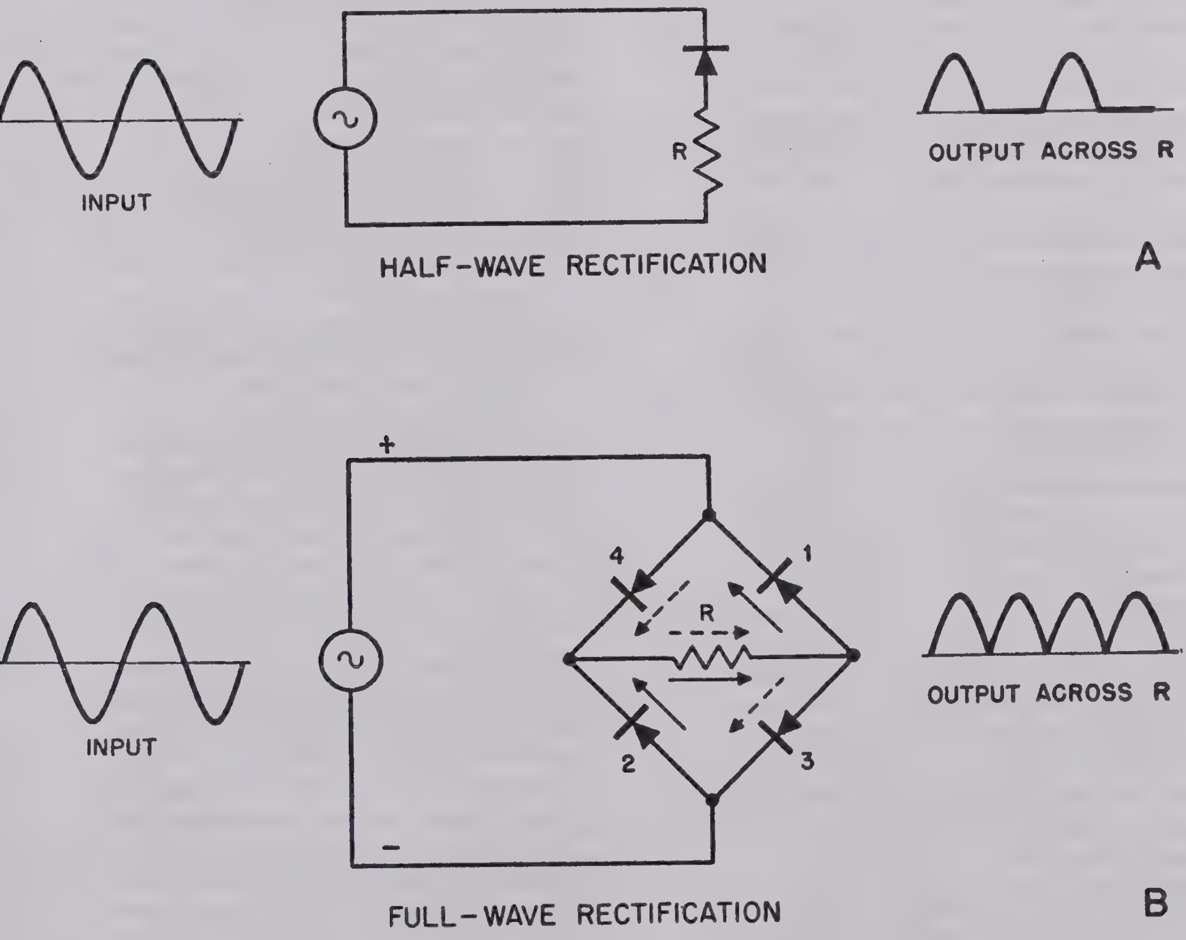


Figure 25. Half-wave and full-wave rectification.

current through the resistor is not changing direction.

c. USE OF D-C METER AND RECTIFIER.

(1) It is possible to measure ac by substituting a d-c movement for either resistor in figure 25. The ac to be measured is changed to pulsating dc by rectifier action, and then passes through the meter coil, allowing the pointer to read the average current. The moving coil cannot follow the instantaneous changes of pulsating dc because of its inertia.

(2) The average current through the coil during full-wave rectification differs from that produced by half-wave rectification. In full-wave rectification, the average current is .637 of the peak value, since both halves of the a-c wave are being used. The pointer, therefore, takes a position corresponding to .637 of the peak value of the current flowing through the meter. The scale, however, is calibrated to read in rms values, or .707 of the peak current being measured.

(3) In half-wave rectification, current flows through the meter during one alternation but not on the other. Because of its inertia, the coil cannot follow all of the instantaneous changes of current over the *whole cycle.* The average current for one alternation is .637 of the peak value, but for the next alternation it is 0. Therefore, the average current for the whole cycle is the sum of both alternations divided by two.

(4) The average current for the whole cycle is (.637 minus 0)/2, or .318 of the peak value. The needle takes a position representing .318 of the peak value of current flowing through it. This point, however, is calibrated at .707 of the peak value, so that the meter reads the rms value of the ac being measured.

d. PRACTICAL RECTIFIER-METER CIRCUIT.

(1) To take voltage readings, multiplier resistors must be placed in series with the meter movement and a copper-oxide rectifier. When this is done, the efficiency of the rectifier is reduced, since no rectifier can be perfect and there must be some resistance. The resistance of the rectifier while conducting, known as the forward resistance, is small. However, the back, or leakage, resistance is not infinite but has a definite value, about 50 times greater than the forward resistance.

(2) For example, assume that a meter movement with 50 ohms resistance is placed in series with a rectifier that has a forward resistance of 1,000 ohms. Within the meter, there is now a total of 1,050 ohms of resistance in one direction and 50,050 ohms in the other, since the back resistance is 50 times the forward resistance. Current for all practical purposes flows in one direction only through the meter (A, fig. 26). Assume that the voltage being measured is large and it is necessary to place 100,000 ohms of multiplier resistance in series with the meter and the rectifier, as shown in B. On one alternation, the total resistance to current flow comprises the multiplier resistance, R, or 100,000 ohms, the forward resistance of the rectifier, R_f, or 1,000 ohms, and the meter-movement resistance, R_m, or 50 ohms. The total resistance is then R plus R_f plus R_m, or 101,050 ohms. On the next alternation, the rectifier does not conduct and the total resistance is 150,050 ohms, since the rectifier resistance, R_b, is now 50,000 ohms (B, fig. 26).

(3) There is little difference in the amount of resistance on each alternation—101,050 ohms in the forward direction compared with 151,050 ohms in the opposite direction. There is almost as much current flowing through the meter movement in one direction as in the other. Consequently, there is only a small deflection of the meter based on the difference between the currents flowing during the two alternations.

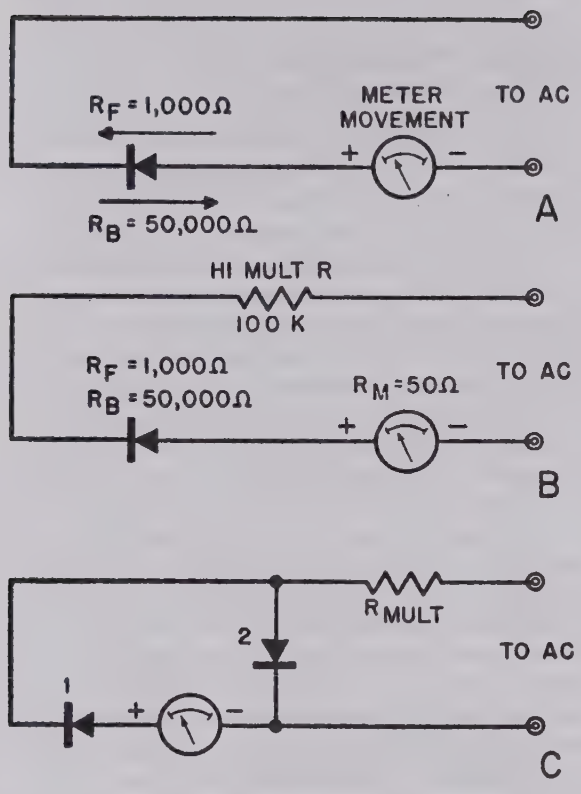


Figure 26. Double half-wave rectifier circuit cuts out loss of rectifier efficiency.

(4) To overcome the inefficient rectification caused by putting a large multiplier resistance in series with the rectifier, a double half-wave circuit generally is used (C, fig. 26). On one alternation, half-wave rectification occurs and current flows through the meter movement and rectifier 1; on the other alternation, current flows through rectifier 2 and bypasses the meter movement and rectifier 1.

e. Additional Design Requirements.

(1) The forward resistance of a copper-oxide rectifier varies with the amount of current flowing through the rectifier, and also varies somewhat in different rectifier units. To compensate for this, the meter circuit must be properly designed or the calibration of the meter will be upset.

(2) Since the forward resistance can vary from 2,000 to 500 ohms as current through the rectifier varies from .1 ma to 1 ma, the calibration of the meter is nonlinear. When a shunt is placed across the meter movement, and both shunt and movement are placed in series with the rectifier (fig. 27) this difficulty is partially overcome.

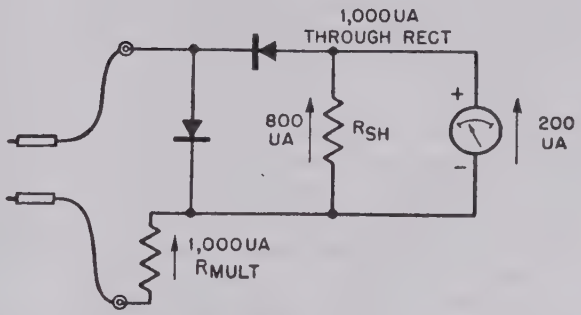


Figure 27. Shunt across meter movement increases current through rectifier but decreases meter ohms-per-volt rating.

(3) For example, if the movement has a sensitivity of 200 μa and the shunt has one-fourth the resistance of the meter movement, then four times as much current will flow through the shunt. When the meter is deflected full scale, 800 μa flows through the shunt, 200 μa through the meter, and a total of 1,000 μa, or 1 ma, flows through the rectifier. Even at low meter readings, a substantial amount of current flows through the rectifier when a shunt is used and the change of rectifier resistance is small.

(4) However, since there is now 1 ma of current flowing through the multiplier resistors at full-scale deflection, the meter effectively has a 1-ma movement instead of a 200-μa movement. Multimeters that have a different ohms-per-volt rating for ac than for dc are common, and in most multimeters the a-c meter is rated at 1,000 ohms per volt.

(5) With a proper choice of shunt values, the scale is more nearly linear and the same set of numbers on a multimeter

scale can be used for ac or dc. Multimeters often have separate scale markings to be used for a-c readings and provide separate scale calibration as well as separate numbers for a-c measurements (fig. 28).

Figure 28. Typical multimeter scale. The a-c volts scale has separate calibration and separate numbers.

(6) Meter circuits can include one or more variable resistors to compensate for rectifier variations when the rectifier unit is changed (R_1 and R_2 in fig. 29). A known a-c voltage is applied and the resistors are varied until the voltage is measured correctly on the scale, and the meter then is said to be calibrated.

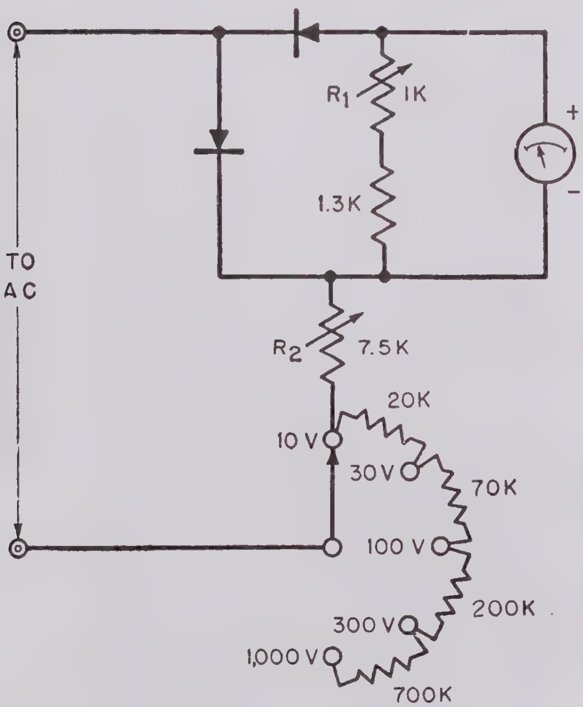


Figure 29. Typical commercial circuit of copper-oxide rectifier meter, 1,000 ohms per volt.

24. Rectifier Characteristics of Copper-Oxide Rectifier Meters

a. RECTIFIER QUALITIES. Copper-oxide rectifiers can last for a long period when not overloaded, but when operated at temperatures above 160° F. they deteriorate rapidly. A typical unit with an area of three-sixteenths inch can handle up to 15 ma of current and has a breakdown voltage of about 11 volts per unit.

b. METER ACCURACY. Since the rectifier inaccuracy adds to the inaccuracy of the moving-coil meter, the over-all accuracy of the meter is usually within 5 percent.

c. FREQUENCY RESPONSE. When the frequency being measured increases, the readings become progressively lower. This is caused by the capacitance (approximately .009 μf) of the copper-oxide rectifier unit. As the frequency increases, the capacitive reactance of the rectifier decreases and acts as a low-resistance path across the rectifier. The readings become one-half to 1 percent lower per 1,000 cps (cycles per second) up to 35 kc (kilocycles). Because of this, these meters generally are not used to measure frequencies above the audio range (15,000 cps). For example, if a 5,000-cps voltage is measured, the meter reads from 2½ to 5 percent low depending on the instrument used.

d. SCALE. The scale tends to be slightly nonuniform at the low end because the forward resistance of the rectifier varies with the current flowing through it.

e. USE AS VOLTMETER AND AMMETER. The copper-oxide rectifier meter can be used either as a voltmeter or an ammeter, but is more commonly used as a voltmeter for low-frequency a-c voltage measurements. Rectifier meters are more sensitive and, therefore, upset circuits less than moving-vane meters do.

25. Comparison of A-C and D-C Meters

a. A-c meters are calibrated to the rms value of a sine wave, although they respond to the average value. When an a-c meter is placed across dc, it reads high by at least 1.11 (form factor) times the voltage being read, but when a d-c meter is placed across ac, it does not regis-

ter at all. The needle of the d-c meter does not move back and forth in step with the changing current because of the inertia of the movement, but remains at 0 and quivers slightly. This does not mean that current is not flowing through the meter. A d-c meter on a low range, placed across a high a-c voltage, can be damaged, even though the needle does not move.

b. It is not necessary to observe polarity when using a-c meters, since the polarity of the voltage is always changing.

c. When nonsinusoidal alternating currents are to be measured, it is necessary to check not only the amplitude, but also the waveshape and the frequency of the ac. Therefore, other instruments, such oscilloscopes, generally are used to measure the amplitude, waveshape, and frequency of nonsinusoidal waves.

26. Summary

a. MOVING-VANE METERS.

(1) Two moving-iron meters are used in electrical work, the radial-vane and the concentric-vane.

(2) The motor system of moving-vane meters works on the principle of two soft-iron vanes, inside a current-carrying coil, becoming magnetized and repelling each other.

(3) Springs are used in the control system of moving-vane meters.

(4) These meters use air damping to brake the needle swing.

(5) They have a *square-law* scale.

(6) The meter movements respond to the average value of current, but the scale is calibrated in the rms value of the sine wave.

(7) Moving-vane meters are not usable at frequencies above 100 cps, are 5 percent accurate, and can be used as voltmeters and ammeters in circuits which will not be upset too much by their low sensitivity.

b. COPPER-OXIDE RECTIFIER METERS.

(1) Copper-oxide rectifier meters are a combination of a copper-oxide rectifier and a d'Arsonval (d-c) meter movement. The rectifier changes ac to pulsating dc, which is measured by the d-c movement.

(2) Copper-oxide rectifiers can be used in half-wave or full-wave rectifier circuits.

(3) Most practical meter circuits use a double half-wave rectifier connection. This eliminates the inefficient rectification resulting from large multiplier resistance in series with the rectifier.

(4) To obtain more linear calibration, many copper-oxide rectifier meters use shunts across the meter movement. To make the calibration more accurate, variable resistors can be placed in shunt or in series or both.

(5) These meters read low as the frequency being measured increases, because of the capacitance of the rectifier unit. The meters are usable through the audio range to about 35 kc, with the readings one-half to 1 percent low per 1,000 cps.

27. Review Questions

a. Which meters can be used for low-frequency a-c measurements?

b. Define ac, cycle, alternation, frequency.

c. Define rms, average, peak.

d. What is the form factor of a sine wave?

e. Explain the operation of a radial-vane meter.

f. Explain the operation of a concentric-vane meter.

g. What damping system is used in moving-vane meters?

h. Why do moving-vane meters have square-law scales?

i. Explain the statement, "Moving vane meters respond to the average current but are calibrated in rms values."

j. Compare the frequency response and sensitivity of moving-vane meters and copper-oxide rectifier meters.

k. Explain the construction and operation of a copper-oxide rectifier meter.

l. What is the effect on the efficiency of copper-oxide rectifiers when a large resistance is connected in series with it? Explain.

m. Draw a practical meter circuit which eliminates the difficulty indicated in question 12.

n. What purposes does a shunt serve in a copper-oxide rectifier meter?

IV. OHMMETERS

28. General

a. The ohmmeter is an instrument that indicates the resistance value of a circuit element or network on a meter scale calibrated in ohms. It is used also to locate shorted or open circuits, check circuit continuity, and provide a rough check on capacitors. The ohmmeter is one of the basic test instruments, along with the voltmeter and ammeter.

b. The ohmmeter consists of a sensitive current meter, a source of low-voltage dc, and some form of current-limiting resistor. The meter usually is a conventional d-c moving-coil type, and a battery supplies the necessary d-c voltage.

c. The values of resistance encountered in electronic equipment vary from fractions of an ohm to many millions of ohms (megohms). Most ohmmeters are constructed to cover a number of ranges from very low to very high resistance by connecting various values of current-limiting resistors in the ohmmeter circuit. The different ranges then can be selected as required by means of individual input terminals or a selector switch. When a selector switch is used, only one set of input terminals, common to all ranges, is necessary. The meter scale can be calibrated to read each individual range directly, or one meter scale can be used and a multiplying factor applied for each range.

29. Series Ohmmeter

a. In the basic ohmmeter circuit of figure 30, a 4.5-volt battery, a variable resistor, R_A, and a fixed resistor, R_B, are connected in series with a milliammeter. The two leads labeled P_1 and P_2 represent test prods which are connected across the resistance to be measured, R_x. The meter is a 0- to 1-ma movement, requiring 1 ma of current for full-scale deflection, and the internal resistance, R_M, is 50 ohms. The fixed resistor, R_B, limits the flow of current and is placed in the circuit to prevent damage to the meter. If no limiting resistor is placed in the circuit and the variable resistor is adjusted to a low value of ohms, the current flow in the circuit becomes excessive. The variable resistor, R_A, adjusts the series resistance in the circuit so that 1 ma flows when the test prods are shorted together. This occurs when the total series resistance is 4,500 ohms (4.5 volts/4,500 ohms equals 1 ma). In the circuit illustrated, the internal resistance of the meter is 50 ohms, the resistance of R_B is 4,000 ohms, and R_A is adjusted to 450 ohms, making up the required series resistance of 4,500 ohms. This gives full-scale deflection on the 0- to 1-ma meter.

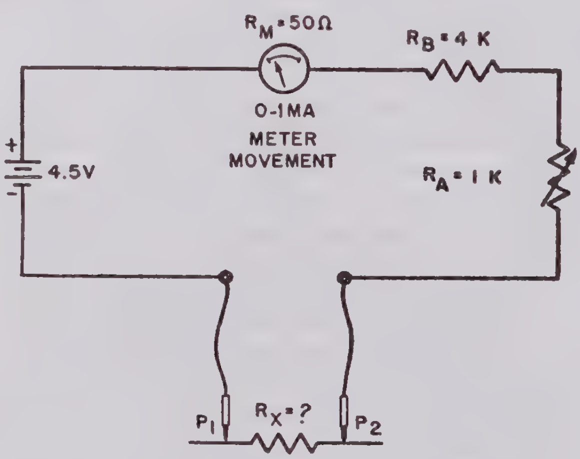


Figure 30. Basic circuit of series-type ohmmeter.

b. When the test prods are shorted, current flows through the circuit and the meter needle is deflected across the scale. A knob on the front of the panel marked OHMS ZERO ADJ (fig. 47) controls resistor R_A, and this is adjusted to provide full-scale deflection of the

meter needle. This position of the needle corresponds to 0 resistance, since the two connected prods are short-circuited across the ohmmeter terminals. In the series-type ohmmeter, full-scale deflection of the meter pointer indicates the lowest resistance; the opposite end of the scale represents the highest resistance.

c. When the battery ages, the available voltage decreases and the variable 0-ohm resistor, R_A, compensates for this condition. The current can be increased to the required value by adjusting R_A, which decreases the total series resistance. The zero-adjusting resistor, R_A, can be connected either in series or in shunt with the meter. When it is connected in shunt, a fixed resistor is connected in series with R_A, and both resistors are connected across the meter. For accuracy in meter readings, a 0-ohm adjustment is made each time the ohmmeter is used.

d. After the ohmmeter has been adjusted for full-scale deflection, the test prods are separated and the meter pointer returns to the open-circuit position on the left of the scale. Placing the prods across the unknown resistor connects it in series with the ohmmeter circuit, the current is reduced proportionately, and the meter pointer no longer deflects full scale. If the value of R_x is equal to the combined resistance of the current-limiting resistor, R_A, and the internal resistance of the meter, the total circuit resistance then becomes 4,500 plus 4,450 plus 50, or 9,000 ohms. The current in the circuit is now I equals E/R, or 4.5/9,000 equals .0005 ampere, or .5 ma. This is half of the 1 ma required for full-scale deflection, and the meter pointer is deflected only half scale.

e. When calibrating the meter scale of the ohmmeter in figure 30, the half-scale deflection point is marked 4,500 ohms. If the value of the unknown resistor, R_x, is twice the resistance of the ohmmeter, the total circuit resistance is tripled, and the current is reduced to one-third the full-scale deflection value. The meter pointer deflects to one-third full scale and corresponds to an R_x of 9,000 ohms.

f. These and other points on the ohmmeter scale can be calibrated conveniently from the formula:

$$R_x = R_c\left(\frac{I_1 - I_2}{I_2}\right)$$

where R_x = unknown resistance
R_c = total circuit resistance with prods shorted together
I_1 = ohmmeter current with prods shorted
I_2 = ohmmeter current with R_x connected across prods.

For example, find the value of R_x when the pointer deflection indicates a flow of .25 ma through the ohmmeter circuit. The value of R_x is now:

$$R_x = 4{,}500\left(\frac{1 - .25}{.25}\right) = 13{,}500 \text{ ohms.}$$

By use of this formula the entire meter scale can be calibrated to read directly in ohms the value of any unknown resistor connected across the ohmmeter test prods. The resistance values increase progressively from *right* to *left*, or from maximum to minimum deflection.

g. The series-ohmmeter circuit cannot be used to measure accurately the low resistances of coils, chokes, and transformer windings, which are often 5 ohms or less. These low values of resistance are so crowded on the right-hand side of the meter scale that distinction between them is impossible. An example of this situation can be shown by using the calibration formula given above. Assume that the ohmmeter scale has 10 divisions with the same circuit conditions as in figure 30. At nine-tenths full-scale deflection, or one division removed from the 0-ohm position, the current is .9 ma. Using the calibration formula to determine the resistance measured with this deflection,

$$R_x = R_c\left(\frac{I_1 - I_2}{I_2}\right) = 4{,}500\left(\frac{1 - .9}{.9}\right) = 500 \text{ ohms.}$$

h. If a resistance of 500 ohms causes the ohmmeter pointer to deflect over nine-tenths of the scale, any value less than 500 ohms must be read within the crowded limits of the final scale division. Consequently, since extremely low values of resistance cannot be read with the simple series-type circuit, other circuits must be used.

30. Shunt Ohmmeter

a. Low values of resistance can be measured accurately by means of a shunt ohmmeter (fig. 31). The unknown resistor, R_x, is shunted across the meter and some of the current in the

circuit takes the path through R_x. The current through the meter is reduced and the amount of deflection drops proportionately. The current flowing through the meter depends on the ratio of the shunt resistance, R_x, to the internal resistance of the meter, R_m. When the meter resistance is known, the value of R_x can be determined from the following formula:

$$R_x = R_m\left(\frac{I_1}{I_1 - I_2}\right)$$

where R_x = unknown resistance
R_m = meter resistance
I_1 = ohmmeter current —R_x not in circuit
I_2 = ohmmeter current —R_x in circuit.

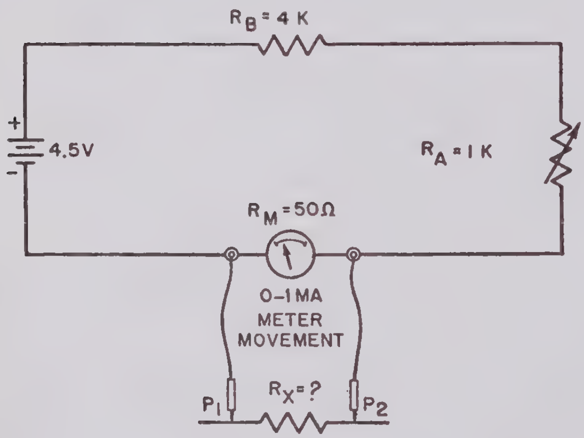


Figure 31. Basic shunt-type ohmmeter circuit.

b. With test prods P_1 and P_2 (fig. 31) open, R_A is adjusted to provide full-scale deflection on the meter, and a current of 1 ma flows through the circuit.

c. The test prods are connected across the unknown resistor, R_x, placing it in shunt with the meter. The 1-ma current in the ohmmeter circuit divides at the junction of the meter and R_x, part of it flowing through R_x and the rest flowing through the meter. The current through the meter is directly proportional to the resistance of R_x and causes a reduced deflection of the meter pointer. For example, the value of R_x is the same as the internal resistance of the meter, or 50 ohms. Because two parallel paths of equal resistance are provided, the current in the circuit divides equally, one-half flowing through the meter and one-half through R_x, so that the pointer deflects only half scale.

d. The entire meter scale can be calibrated by means of the formula given. The indicated resistance value increases progressively from *left to right*, being maximum for full-scale deflection. This is the reverse of the scale used with the series circuit of figure 30.

e. Shunting the meter resistance with resistor R_x has negligible effect on the total resistance of the ohmmeter circuit, since the combined resistance is less than 50 ohms for any value of R_x. Variations of less than 50 ohms in a series circuit having a total of 4,500 ohms represent a small fraction of the total resistance. The increase in current caused by the shunting effect of R_x is only a few microamperes. This small increase in the ohmmeter current has little effect on the ohmmeter readings and can be disregarded for all practical purposes.

f. The usable scale range of the shunt-ohmmeter circuit shown in figure 31 is approximately between 5 and 400 ohms. Resistances falling above or below these values are difficult to read with any degree of accuracy because of the crowding that occurs at the ends of the scale. Should greater accuracy be required for low values of R_x, the meter scale can be extended to provide several low-resistance ranges by incorporating meter shunts having the required resistance values. The desired range then is selected by connecting the proper shunt across the meter by means of individual terminal jacks or a multipole switch. The required shunts usually are connected across the meter by turning a rotary switch to the range indicated on the ohmmeter panel. Values as low as a fraction of an ohm can be measured with considerable accuracy, since a resistance range having very low limits can be spread over the entire meter scale.

g. A shunt ohmmeter providing three ranges for lower resistance measurement is shown in figure 32. With the selector switch in neutral position 3, the unknown resistor, R_x, is connected directly across the meter. This provides a meter range extending to about 400 ohms, as in the circuit of figure 31. When resistor R_1 is switched across the meter, part of the current is shunted around the meter and flows through R_1.

This causes a small deflection of the pointer and provides a lower resistance range, which depends on the value of shunt R_1. Resistor R_2 has a lower value than R_1, and when it is switched across the meter more of the current is shunted through it, and the meter pointer deflects less than before. The result of connecting these shunts across the meter is that progressively lower values of resistance, R_x, are required to return the meter pointer to the left end of the scale; therefore lower values of resistance are read more accurately. As each of the three ranges is used, the meter pointer must be zero-adjusted by means of resistor R_A before the unknown resistor is connected across the test prods. The prods are *not* shorted together for adjustment of this type of ohmmeter.

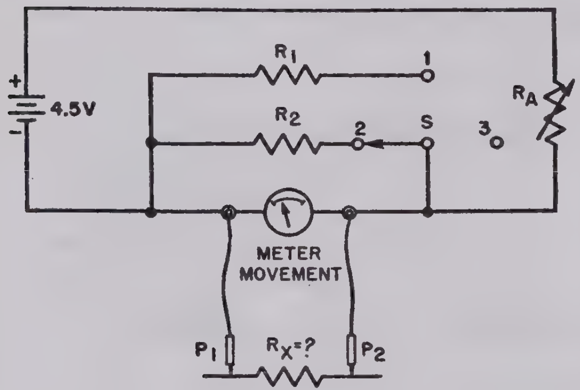


Figure 32. Shunt-ohmmeter circuit providing three low-resistance ranges.

h. With R_x connected in the circuit, the measured resistance readings increase progressively from left to right on the meter scale and maximum resistance is indicated by full-scale deflection.

31. Series Ohmmeter Using Meter Shunts

a. A circuit providing one high-resistance and two low-resistance ranges is shown in figure 33. This is a basic series ohmmeter because the unknown resistor, R_X, is placed in series with the circuit. However, shunts are placed across the meter to read ohms on the lower ranges. It is called a multirange ohmmeter since it will read more than one range.

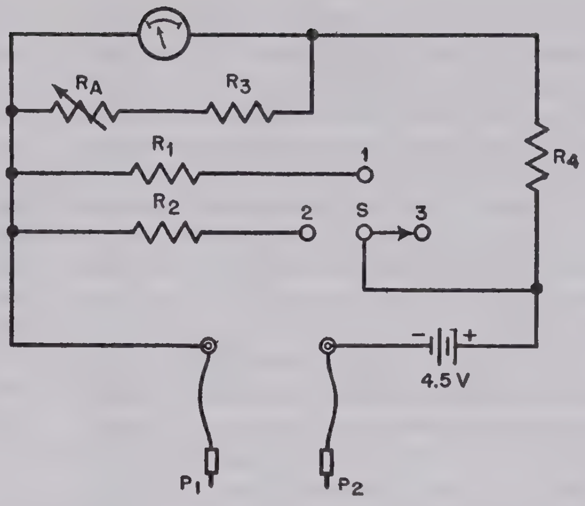


Figure 33. Series ohmmeter circuit using meter shunts.

b. To provide a better zero-adjustment, the 0-ohm adjusting resistor, R_A, and the current limiting resistor, R_3, are connected in series and shunted across the meter. This compensates for any variation in the voltage as the battery ages and permits a more accurate measurement of the unknown resistance than is obtained when R_A is in series with the meter. Resistor R_4 in series with the battery serves to limit the current in the ohmmeter circuit to the approximate value required to provide full-scale deflection on the meter, final adjustment being made by R_A.

c. With the range switch in position 3, the ohmmeter is connected as a series circuit on the high-resistance range, and high values of resistance can be measured when connected across test prods P_1 and P_2. *The test prods must be shorted together when adjusting for 0-ohm.*

d. When a lower resistance range is desired, the range switch is turned to position 1, and R_1 is then in parallel with the meter. Since this changes the series resistance of the circuit, R_A must be adjusted for 0-ohm. A lower range is available on this ohmmeter by turning the switch to position 2 and readjusting R_A.

e. Separate scales can be provided for each range to be read on a multirange ohmmeter. A more practical method, however, is to calibrate the meter in terms of the lowest scale and then to use multiplying factors to obtain the measured values for the other ranges. The multiply-

ing factors for the different ranges of the series voltmeter are usually in multiples of 10, and can be indicated on the panel as R×1, R×10, or R×100. The resistors used must be established according to the value of the multiplying factor. The indicated reading is taken directly as it appears on the scale and multiplied by the proper factor to give the true value. For example, if the reading on the scale is 30 and the range selector switch is set to a multiplying factor of 100, the true value is 30 times 100, or 3,000 ohms.

f. To measure higher values of resistance than can be accommodated on the high range of the ohmmeter circuit in figure 33, a higher value of voltage must be used. Since the current flowing in a circuit is equal to the ratio of the voltage to the resistance (I equals E/R), it is evident that, as the resistance in the circuit is increased, a point is reached where the current is insufficient to cause a deflection of the meter pointer. A higher voltage, therefore, must be used to force sufficient current through the higher resistance. The increased resistance range is directly proportional to the increase in ohmmeter voltage. For example, if the voltage of the battery in the circuit is increased 5 times to 22.5 volts, the resistance range is increased a like amount, and a multiplying factor of 5 must be applied to the existing high-resistance scale to determine the higher values of unknown resistance. An ohmmeter battery of 45 volts increases the high-resistance range 10 times, and so on. The current-limiting resistor, R_4, in the series circuit must be increased in direct proportion to the increase in voltage, becoming 5 times as great for a 22.5-volt battery and 10 times as great for a 45-volt battery. This additional resistance is required to limit the current flow to the required 1 ma for full-scale deflection.

g. The ohmmeter circuit in figure 34 uses two separate batteries, one of 4.5 volts and the other of 45 volts. A low range, two medium ranges, and a high range are available on this meter and selection of the different ranges is accomplished by a dual rotary switch, S_1 and S_2. The two lower ranges and the medium-high range are powered by the 4.5-volt battery. The high range requires the 45-volt battery, which is automatically connected into the circuit when the range selector switch is turned to the high-resistance range (position 4). The range-selector switch consists of two section, S_1 and S_2, which are ganged together mechanically and rotate in step. Resistors R_4 and R_5 are current-limiting resistors. When the 4.5-volt battery is used, resistor R_4 is connected between this battery and the meter, and R_5 is out of the circuit. When the 45-volt battery is switched into the circuit, resistor R_5 is connected in series with R_4 to limit the current flow to the value required for full-scale deflection on the meter. The higher voltage for the high-resistance range can be obtained from a built-in power supply, although this is not general practice.

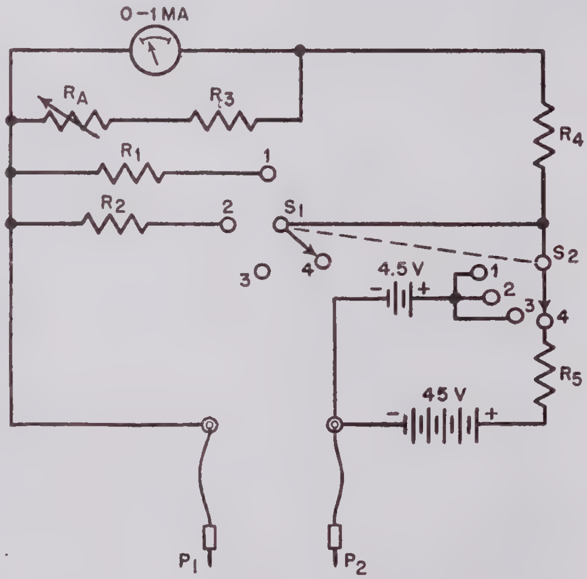


Figure 34. Multirange ohmmeter circuit. High-resistance range is powered by separate 45-volt battery.

h. The test prods must be shorted to adjust the meter to 0-ohm for each range. The shunt resistors for the low ranges are so selected that each resistance range is a multiple of 10, and the meter scale can be calibrated in terms of the lowest range. A multiplying factor then is used to obtain the measured values for each of the other ranges.

i. All the meters used in the ohmmeter circuits discussed to this point have been 0- to 1-ma, or 1,000-ohms-per-volt meters. When a meter having a greater sensitivity (that is, requiring less current for full-scale deflection) is

used, resistances over all ranges can be measured with much smaller battery voltages. A meter rated at 20,000 ohms-per-volt requires a total current of 50 μa (microamperes) through the meter for full-scale deflection. This meter is 20 times as sensitive as the meter with a 1-ma movement, and a much lower source of battery voltage is required for all ranges. The circuit of a commercial ohmmeter providing resistance measurements from .2 ohm through 20 megohms is shown in figure 35. This wide variation in resistance measurement is covered in three ranges: 0 to 2,000 ohms on the low range, 0 to 200,000 ohms on the second range, and 0 to 20 megohms on the high range. The first two ranges are powered by a 1.5-volt battery, and a voltage of 7.5 volts (1.5 plus 6) extends measurement to 20 megohms on the high range.

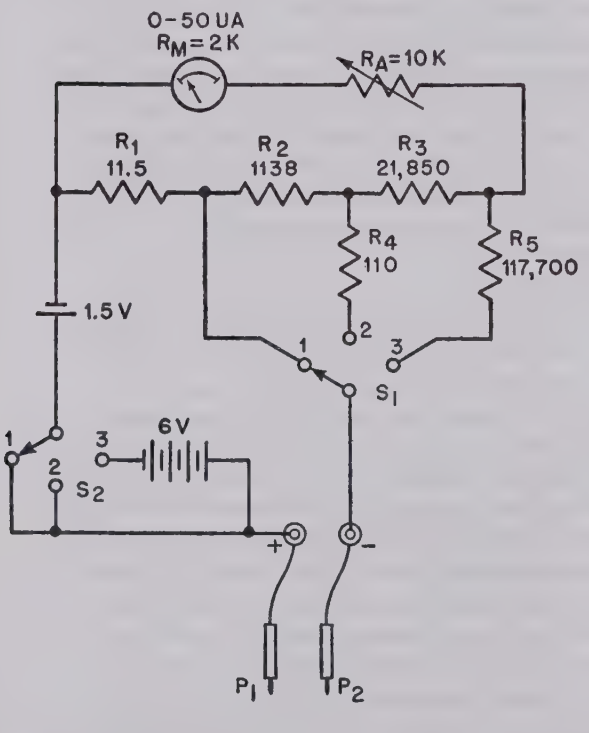


Figure 35. Commercial multirange ohmmeter circuit using highly sensitive 50-µa meter.

j. Switches S_1 and S_2 are ganged together to connect the proper shunt and series resistors in the circuit and, at the same time, to select the correct battery voltage (fig. 35). Test prods P_1 and P_2 must be shorted together and 0-ohm resistor R_A adjusted for full-scale deflection on the meter before each range is used. The meter scale is calibrated in terms of the lowest range and a multiplying factor (indicated on the panel) is used to determine resistance values on the other two ranges. The meter is read from right to left, the highest resistance for each range being at the extreme left of the scale. Five 1.5-volt dry cells are used to supply battery power for the ohmmeter circuit. Shunt resistors are placed across the meter for all ranges to restrict the current flow through the meter to the maximum required for full-scale deflection.

32. Using Ohmmeter

a. Care must be taken to avoid connecting the ohmmeter across circuits in which a voltage exists, since such a connection can result in damage to the meter. Although the power switch normally performs the function of removing applied voltage from the equipment, the switch itself can be defective. Therefore, *to insure the removal of all voltage to the equipment under test, disconnect the source of input voltage by removing the power plug.* Batteries or bias cells to provide fixed bias or other operating voltages may be included in the circuits under test and the ohmmeter must not be connected across these sources of voltage. All capacitors must be discharged before the ohmmeter prods are connected in the circuit, since charges remaining on capacitors after the applied voltage has been removed can damage the meter severely. Because the resistance of circuit elements in a heated condition may differ considerably from that in a cool state it is advisable to wait a few minutes after the power has been removed before applying the ohmmeter to the equipment.

b. When resistance measurements are made in a circuit, each element can be tested individually by removing it from the circuit and connecting the ohmmeter test prods across it. However, this method consumes time, and usually measurements are made from various points in the circuit to a selected common reference point (chassis or B-minus). In this manner, complete sections of the circuit can be measured quickly to determine the presence of abnormal conditions. Charts indicating *point-to-point resistance* values usually are supplied with the equipment. The ohmmeter is connected across the

designated points, and the readings obtained are compared with those on the chart. When an abnormal resistance reading is obtained, each element in the circuit is isolated and tests are made to determine the cause of the abnormality.

c. To avoid erroneous readings when no resistance chart is available, care must be taken to ascertain that other circuit elements are not connected in parallel with the element being measured. The element under test usually can be isolated by opening one of its connections in the circuit.

d. A leaky capacitor connected in parallel with a resistor under test can pass current and will indicate a resistance reading depending on the degree of leakage. The reading obtained on the ohmmeter is the resultant of the circuit resistance and the parallel leakage resistance of the capacitor. With a leaky capacitor in the circuit, a reading is obtained even if the shunt resistor is completely open, and it is necessary to disconnect one end of the circuit element before taking a measurement.

e. The hands of the technician should not come in contact with the metal tips of the test prods, since the resistance of the human body under certain conditions is low, less than 50,000 ohms, and may cause erroneous readings. This is particularly noticeable when a high resistance is being measured. *All resistance measurements should be made with the hands holding the insulated portions of the test prods.*

f. The ohmmeter can check roughly the condition of capacitors and determine the presence of short circuits or leakage. When testing capacitors, other than electrolytics, the ohmmeter selector switch is turned to the highest range, since this provides the highest source of voltage available in the ohmmeter. The meter is observed closely and the test prods are connected to the capacitor. With a good capacitor, the meter pointer deflects slightly and returns quickly to the infinite-ohms position as the capacitor charges across the ohmmeter battery. Small values of capacitors cause a slight deflection of the meter pointer and return quickly to the infinite position; larger values cause a greater deflection and a longer time is taken for the pointer to return. However, if the capacitor is good, the meter pointer will return to the infinite-ohms position in a relatively short time. If no deflection is obtained an open capacitor is indicated, or the capacitance of the unit is too small to cause a deflection. A full-scale deflection of the pointer indicates a shorted capacitor, and leakage is indicated by a steady deflection on some part of the scale. The resistance of a paper capacitor should be over 50 megohms per microfarad, and that of a mica capacitor should be over 100 megohms per microfarad.

g. When testing electrolytic capacitors, the ohmmeter is set to the high range and the prods are connected across the capacitor. Because current passes more readily through the electrolytic capacitor in one direction than in the other care must be taken to observe polarity or the reading obtained will be incorrect. When the prods are connected to the capacitor, a large deflection occurs on the meter and the pointer returns slowly toward the infinite-ohms position as the capacitor takes a charge. Usually, some reading is obtained even when an electrolytic capacitor is fully charged. For a good capacitor rated at 450 working volts dc, the final ohmmeter reading should be over 500,000 ohms. Low-voltage electrolytic capacitors should read at least 100,000 ohms to be acceptable.

33. Summary

a. An ohmmeter is an instrument for measuring resistance.

b. The basic series ohmmeter consists of a meter, a variable resistor, a limiting resistor, and a battery connected in series with the resistor to be measured. The deflection of the meter pointer caused by the current through the series circuit indicates the resistance value on the meter scale, which is calibrated in ohms.

c. Several resistance ranges are required to provide accurate measurement of resistances ranging from very low to very high values.

d. A shunt ohmmeter circuit provides a convenient means of measuring low resistances. In this circuit, the unknown resistor is connected in parallel with the meter movement.

e. Ohmmeters covering a number of resistance ranges are known as multirange ohmmeters.

f. The meter scale on multirange ohmmeters usually is calibrated for the lowest resistance

range. Multiplying factors then are used to interpret meter readings for the higher ranges. Individual ranges generally are selected by means of a range selector switch.

g. In some multirange ohmmeters, the highest range on the meter is powered by a separate voltage source, usually a battery providing higher voltage.

h. Care must be taken when using the ohmmeter to prevent connection of the meter across circuits containing voltage, or the meter can be damaged.

i. In addition to measuring resistance and checking continuity in circuits, the ohmmeter can provide a rough check on the condition of capacitors.

34. Review Questions

a. What is an ohmmeter?

b. What is a series ohmmeter? A shunt ohmmeter?

c. Why are different resistance ranges required in an ohmmeter?

d. How can the low-resistance range on the ohmmeter be extended?

e. How can the high-resistance range on the ohmmeter be extended?

f. When the ohmmeter is calibrated with a single scale, what range does this usually represent?

g. How are the readings obtained on a single scale interpreted to indicate the measurements made on the various ranges?

h. Why must each range be adjusted for 0-ohm before the ohmmeter is used?

i. When resistance measurements are made in electrical circuits, what is the primary precaution to be observed?

j. Should resistance measurements be made across a resistor and a capacitor in parallel? Why?

k. Why must the test prods always be held by the insulated parts?

l. In checking electrolytic capacitors with the ohmmeter, why must polarity be observed?

V. VACUUM-TUBE VOLTMETERS

35. Principles of Vacuum-Tube Voltmeter

a. DESCRIPTION AND USE.

(1) A vacuum-tube voltmeter is an instrument for measuring a-c or d-c voltages and using one or more vacuum tubes in a special circuit containing a meter. The operating power for the tubes usually is obtained from a built-in power supply working off an a-c line, but batteries can be used. Different types of probes are used with the instrument for measuring d-c voltages to very high values and a-c voltages over a wide band of frequencies. The vtvm also is known as an *electronic voltmeter*.

(2) The primary advantage of the vtvm over ordinary meters is its ability to measure voltages without loading the circuit. Normal operating conditions are left more or less undisturbed since the vtvm draws negligible current from the circuit under test. This is of special advantage in low-power circuits where the conventional voltmeter changes the circuit conditions and produces false readings.

(3) The vtvm can be used to measure a-c voltages over a frequency range extending from 5 or 10 cycles to several hundred megacycles. Specially designed instruments have an upper frequency limit of several thousand megacycles and can be used for testing high-frequency equipment.

(4) The vtvm can be used to measure low voltages in high-impedance circuits, since the input impedance of the vtvm usually is standardized at approximately 10 megohms. The loading effect is negligible when this impedance is placed in shunt with the circuit under test, and the measurement of low voltages can be accomplished with a high degree of accuracy. The conventional meter, having much lower input impedance on the low-voltage ranges, loads the circuit and produces erroneous readings.

b. BASIC D-C VACUUM-TUBE VOLTMETER.

(1) The simplest type of vtvm consists of a diode tube, a d-c milliammeter, and a load resistor connected in series with the d-c voltage to be measured (fig. 36). When an unknown voltage, E_x, of the proper polarity is applied to the input terminals, the plate of the diode becomes positive with relation to the cathode, and current flows through the circuit. This current flow, being directly proportional to the applied voltage, deflects the meter pointer accordingly. Since the input impedance of a series-diode circuit is relatively low, a load resistor is used to increase it; this minimizes loading effects of the circuit under test. However, if the load resistor is made large enough to satisfy impedance requirements, a sensitive microammeter must be used to obtain satisfactory deflection with the limited current flow. The value of load resistance chosen, therefore, must be a compromise. This problem is overcome in a vtvm using a triode tube.

(2) The basic d-c vtvm circuit in A of figure 37 consists of a triode, a source of plate voltage, a source of grid bias, and a d-c milliammeter calibrated to read

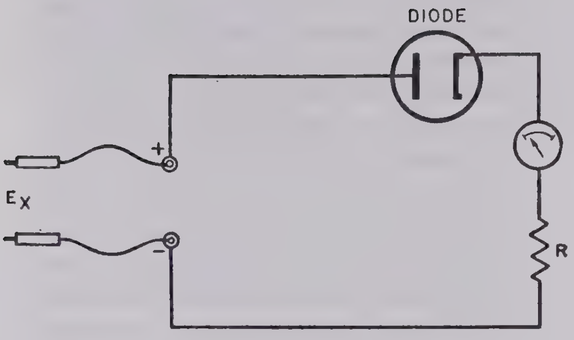


Figure 36. Basic d-c vacuum-tube voltmeter using a diode.

the voltage applied between the grid and cathode of the tube. The negative 5-volt bias on the tube grid establishes the operating point at cut-off, as shown in the grid-voltage plate-current characteristic curve in B. No current flows through the tube with 0 input voltage, and the meter in the plate circuit reads 0. When a voltage is applied to the input terminals, plate current flows through the circuit, actuating the meter pointer.

(3) Since the applied voltage, E_x, causes the tube to operate along the straight portion of the characteristic curve, the increase in plate current is directly proportional. For example, if a voltage, E_x, equal to +2 volts is applied to the voltmeter, the bias on the grid of the tube is reduced to —3 volts, 4 ma of current flows in the plate circuit, and the meter pointer is deflected this amount. This is shown in B by the horizontal and vertical dashed lines which intercept the tube characteristic curve at the indicated points. When E_x is equal to +4 volts, I_p is equal to 8 ma; intermediate values of voltage can be determined by means of the characteristic curve for values of E_x from 0 to +5 volts. The meter scale then can be calibrated directly in terms of voltage.

(4) This simplified triode circuit arrangement is limited in application, since it can be used only for the measurement of d-c voltages having a maximum value of 5 volts. Commercial vacuum-tube voltmeters are designed

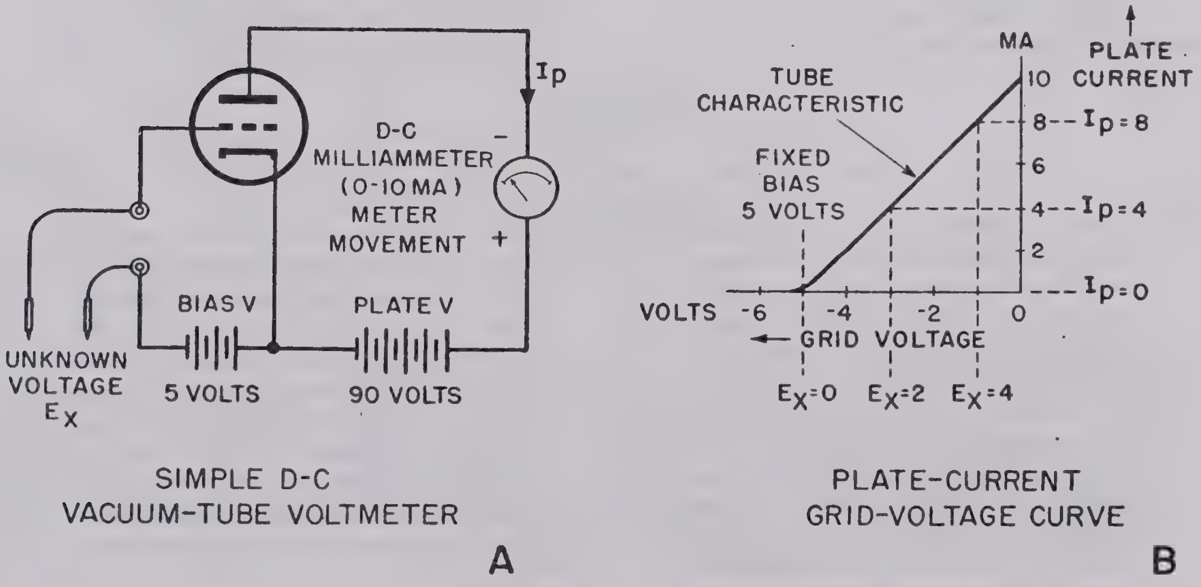


Figure 37. Basic d-c vacuum-tube voltmeter using a triode.

to permit measurement of both a-c and d-c voltages on a number of different ranges from millivolts to many thousands of volts.

c. Basic A-C Vacuum-Tube Voltmeter.

(1) A simple circuit for the measurement of a-c voltages is shown in A of figure 38. Although this circuit is the same as that used for the measurement of d-c voltages it can be used to measure a-c voltages from 0 volts to 5 volts over a wide frequency range.

(3) Conduction of current on the positive alternations of the applied a-c voltage produces current pulses having the waveform shown in B. The meter pointer is unable to follow these current pulses to indicate *peak* values, but responds to the *average* value of the current flowing in the circuit. An examination of the plate-current waveform shows the average value of the pulse at maximum plate current to be 3.2 ma. By selecting a meter which

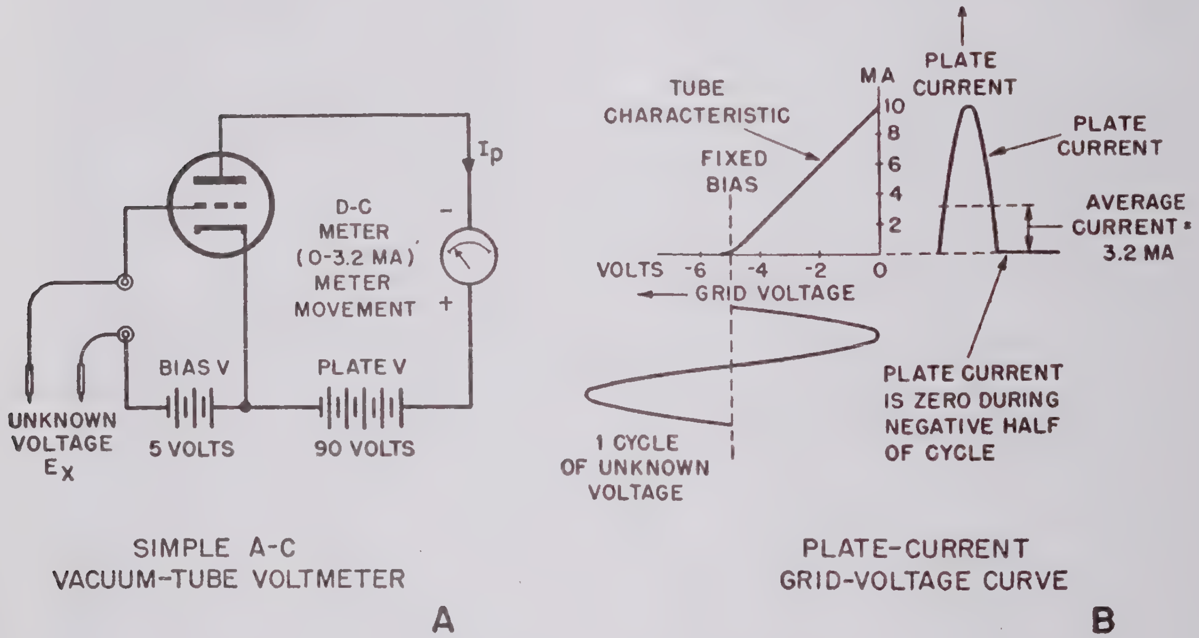


Figure 38. Basic a-c vacuum-tube voltmeter.

(2) When no voltage, E_x, is applied to the input terminals, the tube is at cut-off because of the negative 5-volt bias on the grid of the tube, and the meter reading is 0. This point is marked on the grid-voltage plate-current curve in B. When an a-c voltage is applied at the input terminals, the positive alternation reduces the negative grid bias in direct proportion to the value of the positive half-cycle and the tube draws current. Since the tube is biased to cut-off, the negative alternation has no effect on circuit conditions.

requires 3.2 ma for full-scale deflection, maximum deflection is obtained when the peak positive alternation of the input voltage is equal to 5 volts, and grid bias is reduced to 0. The meter then can be calibrated in terms of *peak* a-c voltage, since the current through the meter is determined by the applied input voltage. A-c vacuum-tube voltmeters can be calibrated to read average, peak, or rms values.

d. Probes.

(1) A probe is a test prod designed for a specific meter application and con-

nected by means of a cable to the input terminals of the meter. Some probes increase or decrease the input resistance or capacitance of the voltmeter; some act to isolate the dc and to minimize the loading effect of the d-c voltmeter on circuits carrying a-f and r-f signal voltages; some use extremely high resistance to act as multipliers. Where the unknown voltage must be rectified before it is applied to the voltmeter, the rectifier unit usually is mounted inside the probe.

(2) The simplest probe used with vtvm's in measuring d-c voltages is one having a series resistor mounted inside. The value of this resistor may be between 1 and 5 megohms, but 1 megohm is the value most commonly used. The purpose of this resistor is to prevent the loading or detuning of a circuit when using the probe to make d-c voltage measurements.

(3) One probe used to measure a-c voltages has a small capacitor of approximately .5 $\mu\mu$f (micromicrofarads) that is connected in series with the input. The capacitor reduces the input capacitance of the voltmeter to a low value and reduces detuning effects when making a-c measurements in tuned circuits. The capacitor also blocks any d-c voltages from appearing in the voltmeter, and prevents the measured a-c voltage from being affected by the presence of a d-c voltage.

(4) The germanium-crystal probe has an extended high-frequency response and a low input capacitance, and is used widely for the measurement of high-frequency a-c voltages. It has the disadvantage of not being able to withstand high voltages.

36. Types of Vacuum-Tube Voltmeters

a. RECTIFIER-AMPLIFIER VTVM.

(1) A block diagram of a vtvm used in servicing communication equipment is shown in figure 39; the basic circuit is shown in figure 40. A-c and d-c voltages over several higher ranges can be measured by means of external multipliers. The amplifier section of the voltmeter contains two triode tubes, V2 and V3, in a balanced circuit. The d-c meter has a current sensitivity of 200 μa and is connected in the amplifier section. For the measurement of a-c voltages a probe with a rectifier tube incorporated is connected to the input terminals of the

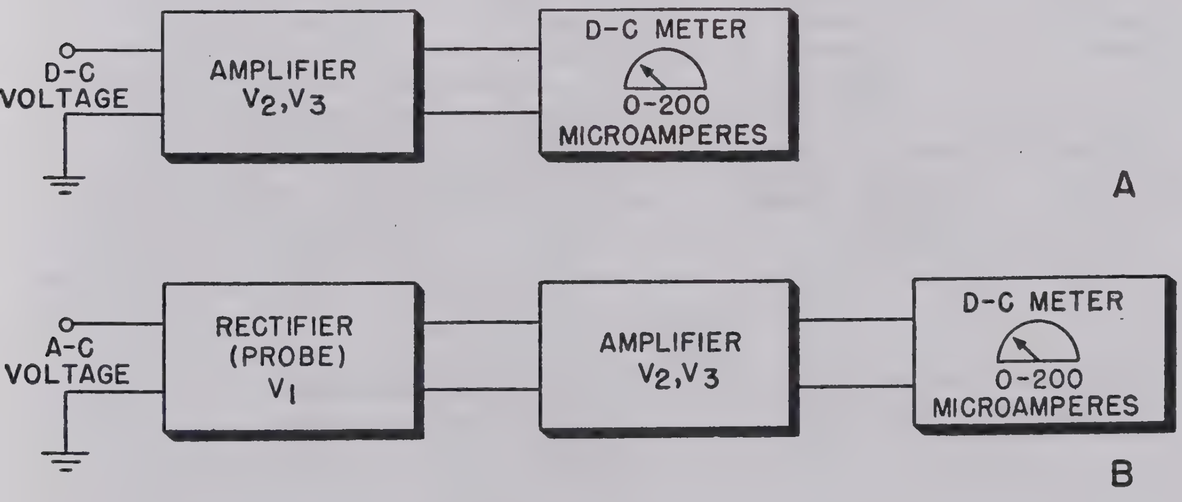


Figure 39. Block diagram of rectifier-amplifier vacuum-tube voltmeter.

amplifier through a short length of shielded cable. Operating voltages for the tubes are obtained from a built-in power supply (not shown), and each separate a-c or d-c range is selected by means of push buttons on the panel.

(2) The basic circuit (fig. 40) of the amplifier section is a balanced d-c amplifier. The meter switching arrangement permits circuit A to measure negative d-c voltages and circuit B to measure positive voltages. The 300-volt power-supply voltage is divided so that a positive 150 volts is applied to the two triode plates through potentiometer R_5, and a negative voltage is applied to the cathodes of the two tubes. Potentiometer R_5 is the 0-ohm adjustment on the panel, and permits adjustment of the plate voltage to compensate for differences in the characteristics of the two tubes. The d-c microammeter is in series with range-calibrating resistors R_A and R_B and is connected between the two cathodes.

(3) With equal voltages on the plates of the tubes and no voltage applied to the voltmeter input terminals, the current through each tube is of equal value. Since equal currents flow through both cathode resistors, the voltage drop across each one is the same, the potential between cathodes is the same, and the meter indicates 0. When an unknown voltage is applied to the grid of either tube in figure 40, one tube draws more current than the other, the circuit is unbalanced, and current flows through the meter. By properly calibrating the meter scale, the amount of plate-current deflection is made directly proportional to the value of the applied voltage.

(4) When a negative 10 volts dc is applied to the grid of V_2 in circuit A, the voltage across R_{25} causes the cathode of V_2 to become less positive, and the cathode of V_3 becomes more positive. A current flows from the cathode of V_2 through the meter and calibrating resistors R_A and R_B to the cathode of

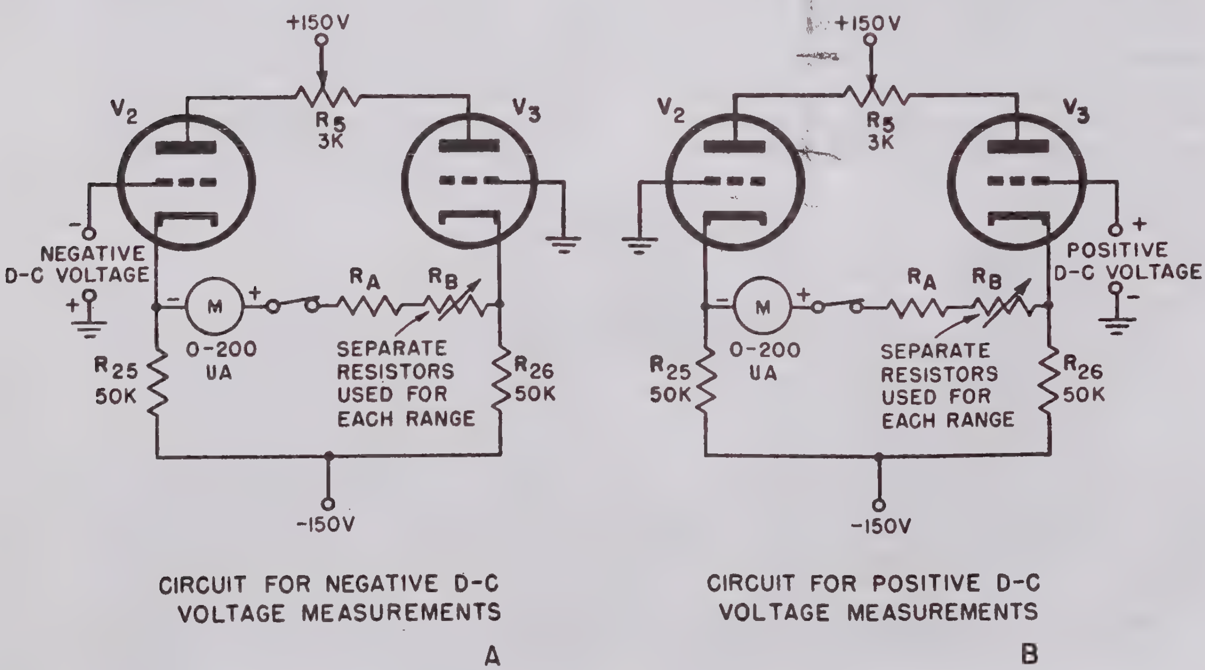


Figure 40. Simplified schematic diagram of balanced d-c amplifier.

V_3, and the meter pointer deflects over the scale. Since the deflection is proportionate to the value of the unknown voltage applied to the tube, the point of deflection can be calibrated as 10 volts on the meter scale.

(5) If the unknown voltage is positive in polarity, it is applied to V_3, in circuit B. A positive voltage on the grid of V_3 makes the cathode of V_3 more positive than the cathode of V_2, and current flows through the meter from V_2 to V_3. The current flows the same way through the meter for the measurement of either positive or negative voltage. A two-circuit switch is incorporated in the meter circuit to switch the input terminals from one tube to the other when measuring positive or negative voltages. When voltage of either polarity is applied to one tube, the grid of the other tube is grounded to satisfy the operating conditions.

(6) Separate sets of calibrating resistors are switched in series with the meter for each voltage range. One of these resistors, R_A, always is fixed, and the other resistor, R_B, is variable to enable the voltmeter to be calibrated accurately. These calibrating resistors act as multipliers, and when the voltage to be measured is increased in value, the resistors also must be increased so that the current flow through the meter is limited to the maximum rated 200 μa required for full-scale deflection. The circuit is fairly stable for the higher voltage ranges but, on ranges of 3 volts or less, resistor R_B in series with the meter is low in value and the stability of the circuit is not as good.

(7) A probe containing a dual diode, which rectifies the a-c voltage before it is applied to the amplifier circuit, is used when a-c voltages are being measured (fig. 41). Although the diode tube is shown adjacent to the schematic of the amplifier circuit, it is located in the probe and connected to the voltmeter circuit by a cable. The voltage to be measured is applied to one-half, V_1-*A*, of the dual diode; the other half, V_1-*B*, is connected to the grid of V_3.

(8) With no voltage applied to rectifier diode V_1-*A*, the plate of the diode is approximately 1 volt negative in relation to ground. This voltage, called contact potential, is the result of electrons leaving the heated cathode with

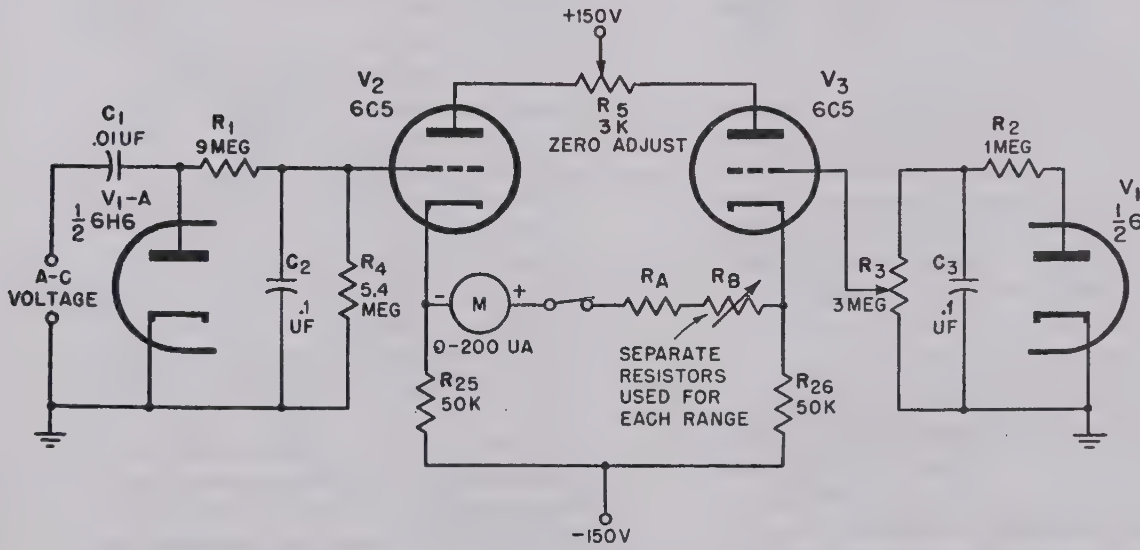


Figure 41. A circuit for measuring a-c voltages.

sufficient velocity to reach the plate of the tube. This flow of electrons causes a voltage drop across the plate load of about 1 volt and appears at the grid of tube V_2, unbalancing the amplifier. To compensate for this, and restore the amplifier circuit to perfect balance, an equivalent potential is applied to the grid of tube V_3 by connecting diode section V_1-B to the grid of V_3. The correct value of contact potential to counteract the effect of the voltage on the grid of V_2 is obtained by adjusting potentiometer R_3 until the amplifier circuit is balanced properly. This condition exists when the meter reads 0 with 0 voltage applied to the voltmeter.

(9) Diode V_1-A functions as a half-wave rectifier, and the rectified current flowing through R_1 and R_4 drives the grid of V_2 negative. This negative voltage unbalances the circuit and causes a current to flow through the meter that is proportionate to the applied voltage. Capacitor C_2 filters the rectified voltage and C_1 serves to block any d-c voltage present in the circuit being measured.

(10) Different sets of calibrating resistors are required for each of the a-c voltage ranges. The meter scale for ranges of 3 volts or less is nonlinear because the diode does not provide linear rectification at low voltages.

(11) Placing the rectifier in the probe permits the use of the basic d-c amplifier circuit for all a-c measurements. When the applied a-c voltages are rectified in the probe, a wider frequency range is available, since cable capacitance and inductance have no effect on d-c voltages.

b. Amplifier-Rectifier VTVM.

(1) Although the rectifier-amplifier type of vtvm can measure voltages over a wide range of frequencies, it is limited in sensitivity since low values of signal voltages, in the order of millivolts, cannot be measured. By connecting one or more resistance-coupled amplifier stages ahead of the rectifier, voltages in the order of microvolts can be amplified sufficiently to be read on the meter. Because of frequency discrimination in the amplifier stages, the amplifier-rectifier vtvm is not readily applicable to the measurement of very high r-f voltages. It is widely used, however, in the measurement of audio and radio frequencies up to several megacycles. Depending on the particular circuit arrangement and application, it is called the audio-frequency, logarithmic, or wide-band vtvm.

(2) The circuit in figure 42 provides multi-range operation from 1 millivolt to 100 volts and uses two stages of amplification before rectification. The high range can be extended by means of multipliers to accommodate several thousand volts. The frequency range extends from 10 cps (cycles per second) to 150 kc (kilocycles). For simplicity, triode tubes are shown in the amplifier stages, but pentodes are used in the actual instrument. Following amplification, the input voltage is rectified by means of a dry-disk rectifier, and the meter is actuated by the rectified current flowing through it. A portion of the output voltage is fed back to resistor R_1 in the cathode of V_1 to stabilize the instrument.

(3) In operation, the unknown a-c voltage is applied to the grid of V_1 through the range-selector network, and amplified. From there the voltage is coupled to the second stage, where it undergoes further amplification. The amplified voltage then is fed through coupling capacitor C to the final circuit consisting of the rectifier in series with the meter. Resistor R_2 limits the current through the meter. When the voltage at C is positive, current flows through the rectifier circuit. Simultaneously, the voltage developed across R_1 increases the negative bias on V_1 and reduces the over-all gain of

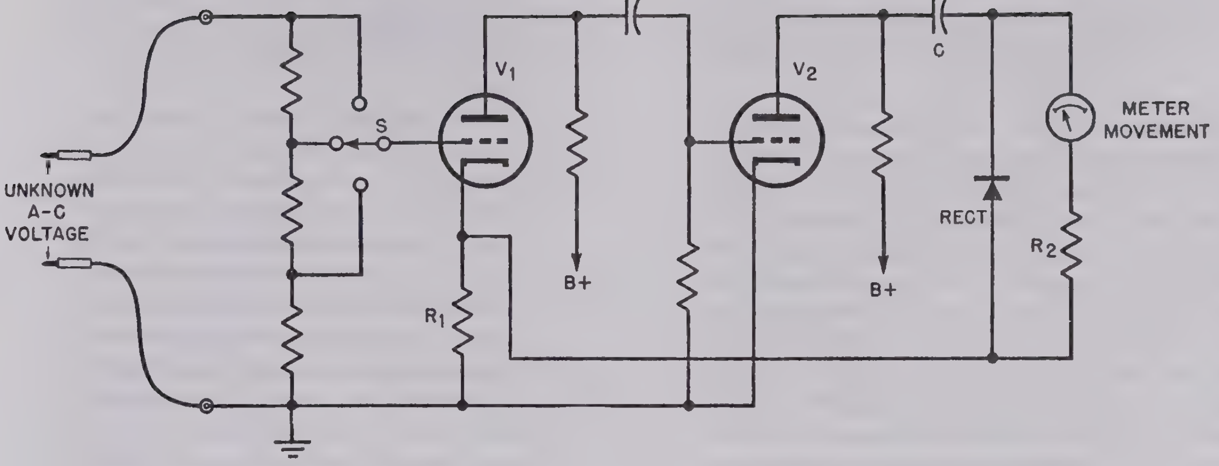


Figure 42. A two-stage amplifier-rectifier vacuum-tube voltmeter using negative feedback.

the amplifier stages, with attendant increase in stability.

c. SLIDE-BACK VTVM.

(1) The basic circuit of a slide-back vtvm used in specialized applications is shown in figure 43. This voltmeter is not a direct-reading type such as those previously described.

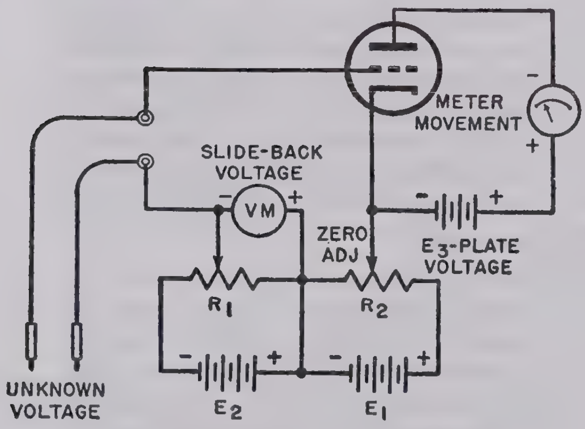


Figure 43. Basic circuit of slide-back vacuum-tube voltmeter using triode.

(2) Potentiometer R_1, which determines the slide-back voltage, is adjusted to produce a 0 reading on the voltmeter. The input terminals then are shorted together, and potentiometer R_2, labeled ZERO ADJ, is adjusted to provide a small reading ($\frac{1}{10}$ or $\frac{1}{20}$ of full scale) on the microammeter in the plate circuit of the tube. Potentiometer R_1 then is readjusted to place a high negative voltage on the grid of the tube. This prevents overloading when the input voltage is too high. The unknown voltage then is connected to the input terminals of the meter.

(3) The effect of the applied input voltage is to cancel some or all of the bias voltage on the grid, and to increase the current flow through the tube. To find the value of the input voltage, the slide-back voltage potentiometer, R_1, is adjusted until the plate current is reduced to the initial value ($\frac{1}{10}$ or $\frac{1}{20}$ of full scale) when no d-c voltage was applied to the input. The reading on the voltmeter then is the value of the applied voltage. The value of the unknown voltage is indicated on the voltmeter when the slide-back voltage and the unknown voltage are equal. With the voltages equal in value, reading the value of the slide-back voltage indicates the value of the unknown voltage.

(4) In some slide-back voltmeters, a single meter is used to indicate the current null point when the slide-back voltage

is adjusted. The unknown voltage is obtained by setting the slide-back potentiometer along a scale calibrated for this purpose.

d. TUNED VTVM. Although vacuum-tube voltmeters usually respond with equal accuracy to a-c voltages over a wide range of frequencies, certain applications require a voltmeter which is frequency selective. To obtain greater sensitivity, one or more tuned stages of amplification can be connected ahead of the meter circuit. The tuned circuit is made variable over a band of frequencies, and any frequency within these limits can be selected and measured. The tuned vtvm finds application in signal tracers, harmonic analyzers, and similar instruments.

37. Using VTVM

a. PRECAUTIONS.

(1) The vtvm is a sensitive measuring device, and subjecting it to a voltage above its rated limit may damage the instrument. *Always connect the voltmeter across a circuit with the range switch initially set on the highest range.* If this does not give a sufficient needle deflection, decrease the range by steps until a convenient reading is obtained.

(2) When using probes for high-voltage checking, always grip the probe near the rear of the handle. This reduces the electric-shock hazard and also decreases the capacitive effects of the hands on the circuit. *If possible, connect the probe to the high-voltage circuit under test before turning on the voltage in the circuit.* High d-c voltages, when present in a-c circuits under test, charge the input coupling capacitor of the meter. If the a-c probe and a ground point are touched at the same time, a dangerous shock may result. To prevent this, *ground the a-c probe immediately after testing such circuits.*

(3) Other precautions to follow for high-voltage measurement are:

(*a*) Locate all high-voltage points in the circuit under test *before* making measurements.

(*b*) Always work with one hand in your pocket.

(*c*) Make sure that no part of your body touches ground at any time.

(*d*) Any point in a piece of defective equipment may contain high voltages. Use the probe when in doubt.

(*e*) When measuring current in high-voltage circuits, always break the circuit at or near ground potential.

(4) In high-frequency measurements using an r-f probe, the ground point for the probe should be as close to the measurement point as possible. *Lead wires, no matter how short, cause substantial voltage drops at high frequencies.* For this reason, it is very important to connect the high side of the voltmeter to the exact point where a reading must be taken.

(5) The a-c ranges of vtvm's are calibrated to read the rms (root mean square) value of a sine-wave voltage. Therefore, when voltages other than sine wave are measured, true readings cannot be taken unless the vtvm measures peak-to-peak voltages. The vtvm is not recommended for measurement of nonsinusoidal voltages except where accuracy is not required and only comparison measurements are desired. The calibration of the vtvm should be checked at frequent intervals.

b. APPLICATIONS.

(1) To operate the vtvm, turn on the power switch and allow the meter to warm up for several minutes. Set the meter needle at 0 by using the zero-adjustment knob on the front panel. If the needle does not drift from the 0 setting, measurements may be made. The exact operating procedure for the various ranges of the instrument vary with the different types and are described in the instruction manual for each meter.

(2) Because of its high input impedance, the vtvm is useful for making voltage

measurements in relatively high-impedance circuits. For example, a vtvm with an input impedance of 10 megohms is used to measure the voltage drop across a 2-megohm grid-leak resistor. The total resistance of the resistor and the meter in parallel is 1.7 megohms. This is so close to the value of the resistor that the current drawn will be practically the same with or without the voltmeter in the circuit. Therefore, voltage measurements can be made without disturbing circuit operation. Similarly, voltage measurements can be made in tuned circuits where the impedance of the various elements is critical and a slight change of the impedance of the circuit (as results when using low- or moderate-impedance measuring instruments) can disturb circuit operation.

(3) Because of its wide frequency range, the vtvm is particularly suitable for measurement of gain in an amplifier stage. This is accomplished by measuring the voltage output of the amplifier for various frequencies and dividing this reading by the voltage input. Such measurements can be made on a single stage (fig. 44), or on a group of stages taken together. The voltage input to the stage or stages is furnished by a signal generator, a device which furnishes a continuous-wave signal with constant peak amplitude at various frequencies.

(4) Vtvm's can be used to locate defects in radio receivers and transmitters by applying a source of signal voltage to the input of the receiver or transmitter, and measuring the voltage developed at every critical point. The amplifier-rectifier vtvm is used for this method of signal tracing because the voltages at some points in the circuit are small and must be amplified before they are measured. Tuned amplifier-rectifier vtvm's are used in commercial signal-tracing instruments for measurement of distortion, hum, and amplifier gain. These measurements help to determine the stage in which defects exist, and the process is called defect localization. Other measurements possible with the vtvm include the checking of avc (automatic-volume-control) voltage, discriminator voltage (in f-m receivers and radar sets), and the grid-bias voltage of oscillators.

38. Summary

a. A vtvm is a voltage-measuring instrument using vacuum tubes and a meter.

b. The advantages of the vtvm over ordinary meters are—higher input impedance, higher sensitivity, greater overload protection, and wider frequency range for a-c measurements.

c. A simple type of d-c vtvm uses a triode with the grid biased initially at cut-off and a meter placed in the plate circuit. When a pos-

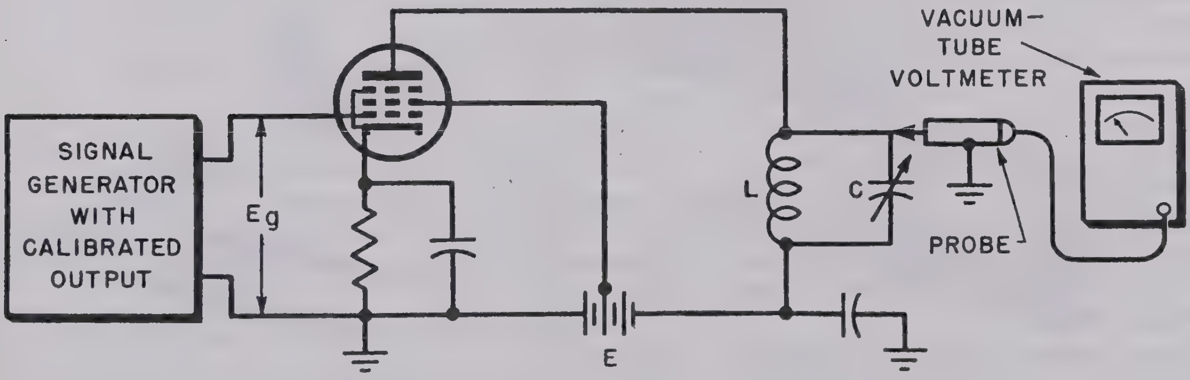


Figure 44. Measuring gain of an r-f amplifier stage with vacuum-tube voltmeter.

itive unknown voltage is fed to the grid, the negative bias voltage is reduced, and plate current flows through the meter in proportion to the input voltage.

d. The same circuit can be used to measure a-c voltages. Plate current flows only during the positive alternation of the unknown voltage, and the meter responds to the *average* value of the input voltage. The meter scale can be calibrated to read average, rms, or peak values.

e. A probe is a device used with a meter for measuring various points within an electrical circuit. It contains a circuit designed either to isolate the vtvm from the circuit under test, or to rectify an unknown a-c voltage to be measured by the meter.

f. The most popular vtvm's are the rectifier-amplifier, the amplifier-rectifier, the slide-back, and the tuned types.

g. The rectifier-amplifier type consists of a rectifier stage (which can be incorporated in the probe), followed by one or more d-c amplifier stages, and a d-c meter connected in the amplifier section.

h. Generally, balanced d-c amplifiers are used in vtvm's. The application of an unknown voltage to the meter results in a condition of unbalance in the amplifier, causing a current to flow through the meter in direct proportion to the value of the unknown voltage.

i. With no external voltage applied to a diode, there is a small current through the diode because the plate traps a small number of the electrons constantly emitted by the heated cathode. The voltage drop resulting at the plate is called the contact potential. To balance this contact potential, a dual-diode is used. The contact potential of one diode is used to nullify the contact potential of the other.

j. By rectifying the a-c voltage and applying it to a d-c amplifier, the rectifier-amplifier vtvm is able to measure a-c voltages over a wide frequency range.

k. Amplifier-rectifier vtvm's are useful for low-voltage a-c measurements where the unknown voltage first must be amplified to give an appreciable reading.

l. Slide-back vtvm's work on the potentiometer principle; that is, the unknown voltage is balanced by adjusting an internal source of voltage in the meter. This is useful for *peak* a-c measurements.

m. In tuned vtvm's, a tuned circuit is incorporated in the instrument ahead of the meter to select a desired frequency. Only voltages of this frequency are measured.

n. The vtvm is a sensitive instrument that can be damaged if mishandled. Proper precautions for its use are included in the instruction book furnished with it, and should be observed.

o. Vtvm's are particularly applicable for voltage measurements in high-impedance circuits, for amplifier-gain measurements, and for signal tracing.

39. Review Questions

a. What are the advantages of the vtvm as compared with ordinary voltmeters?

b. Why is the current through the meter in a simple triode, d-c vtvm proportional to the unknown voltage fed to the grid?

c. Explain the operation of the simple a-c triode vtvm.

d. Name four types of probes. What is each type used for?

e. Why are balanced d-c amplifiers used in vtvm's? How do they work?

f. Why is the rectifier-amplifier vtvm capable of measurements over a wide frequency range?

g. How is a vtvm made to have different voltage ranges? Why is the low-voltage range of the vtvm sometimes inaccurate?

h. When is the amplifier-rectifier type used? Slide-back type? Tuned?

i. Explain the operation of the slide-back type.

j. Give five precautions that should be observed when using the vtvm for high-voltage measurements.

k. Why do most vtvm's give misleading readings when used to measure nonsinusoidal voltages?

l. How is a vtvm used to find the gain of an amplifier?

VI. MULTIMETERS

40. General

a. A multimeter is an instrument incorporating two or more meter circuits and a meter movement in a single case. A typical multimeter (fig. 45) contains voltmeter, ammeter, and ohmmeter circuits using a single meter movement. They may, however, be designed for many specific applications, such as measuring both resistance and capacitance, a-c voltammeters, and d-c voltmeter-millivoltmeters. The multimeters described in this chapter are those used for voltage, current, and resistance measurements.

b. To select the proper circuit for measuring voltage, current, or resistance, either a rotary selector switch or a set of pin jacks is mounted on the instrument panel. The rotary selector switch consists of many sections (wafers) of

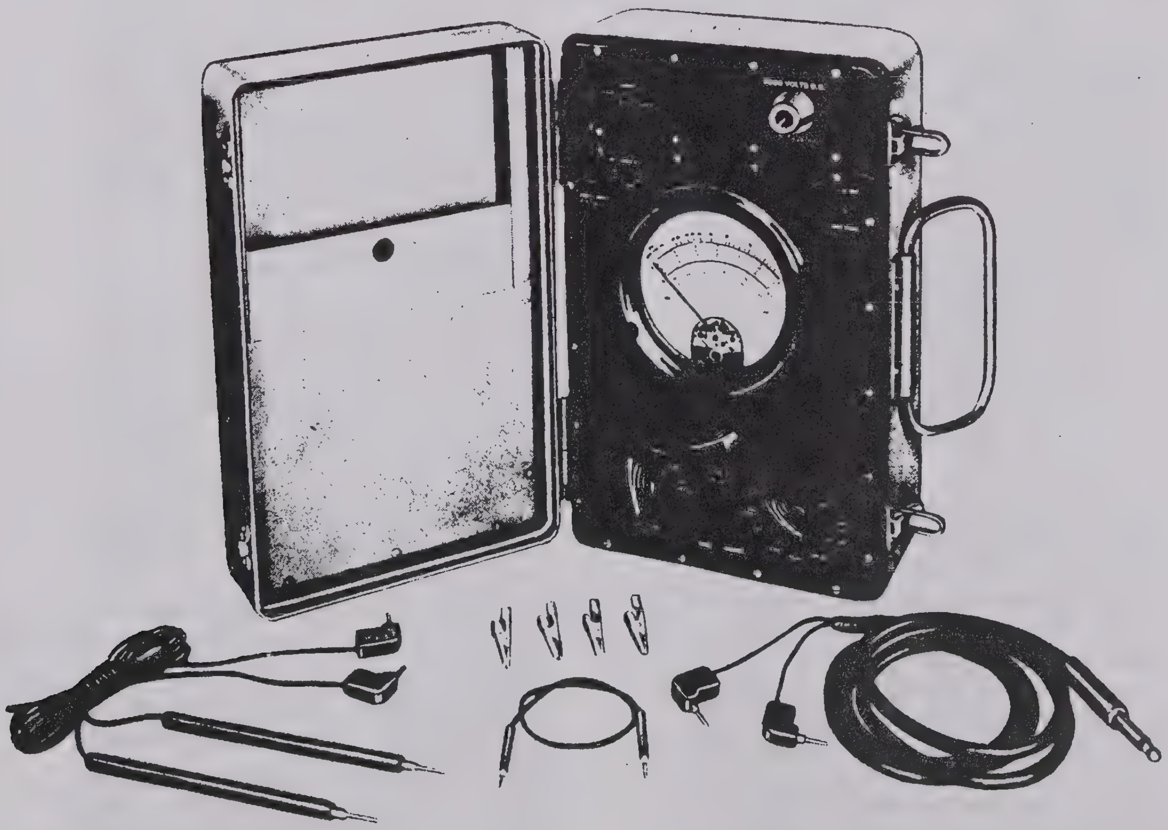


Figure 45. Portable volt-ohm-milliammeter used in measurement of a-c and d-c voltages, direct current, and resistance.

insulating material with switch contacts attached. Each position on the switch corresponds to a particular measuring circuit in the instrument. When the switch is in the d-c voltage position, for example, a contact on each wafer of the switch connects a particular element (meter movement, resistor network, or shunt) into the measuring circuit. In many multimeters, two rotary switches are used, one selecting the measuring circuit, and the other the range. The number of ranges available for the measurement of voltage, current, and resistance varies from meter to meter.

c. When two rotary switches are used, only two pin jacks are necessary on the panel of most multimeters although separate pin jacks may be provided to protect the instrument against damage on the high a-c and d-c voltage ranges. When one rotary switch is used to select the desired measuring circuit, however, separate pin jacks may be needed for each range.

d. For simplicity of reading, most multimeters have three scales, one for resistance measurements, one for d-c volts and milliamperes, and another for a-c volts. The scales usually are provided with a single set of calibration marks and with one or more sets of numerals at the major marks or dimensions. Selection of the individual ranges of measurements to be used determines the multiplying factor to be applied. For example, if the meter d-c voltage ranges are 0 to 10, 50, 250, 500, and 1,000 volts, only three calibrations are required on the indicator scale (fig. 46). The values for the 0- to 10-, 50-, and 250-volt ranges are read directly off the scale. For the 0- to 500-volt range, the 0-to-50 calibration is used, and each reading is multiplied by 10. If a value of 350 volts is being measured, the needle points to 35 on the 0-to-50 scale. Multiplying 35 by 10 gives the true value of 350 volts. Similarly, when measuring resistance with the range selector switch at the R×100 setting, each reading on the ohmmeter scale is multiplied by 100 for the true measured resistance value.

e. In general, there are two multimeters, the volt-ohm-milliammeter, and the electronic multimeter. The volt-ohm-milliammeter combines conventional voltmeter, ammeter, and ohmmeter circuits with a d'Arsonval moving-coil meter movement for d-c measurements. For a-c voltage, a rectifier is added to the circuit. The electronic multimeter combines a vacuum-tube voltmeter with conventional ammeter and ohmmeter circuits.

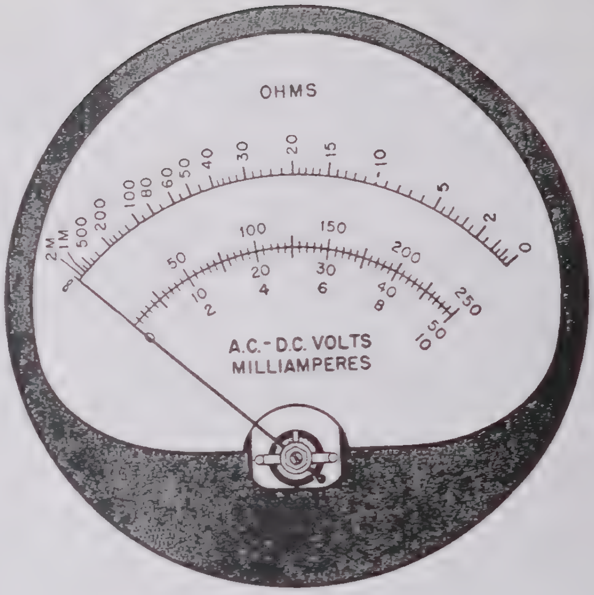


Figure 46. Resistance, a-c, and d-c scales of typical multimeter.

41. Volt-Ohm-Milliammeter

a. GENERAL.

(1) Despite the recent advances in the design and manufacture of meters, the conventional volt-ohm-milliammeter remains the most common equipment for general electrical measurements. Most of these instruments use 50-μa to 1-ma meter movements. The 50-μa meter is used to achieve d-c voltage sensitivities of 20,000 ohms per volt, and is adequate for most d-c measurements, since circuit operation is not greatly affected. Less sensitive meters provide 1,000- or 5,000-ohms-per-volt sensitivity, but care must be taken when using these instruments that circuit operation is not upset. Most a-c voltmeter circuits are designed for 1,000 ohms per volt.

(2) The panel switches and jacks on volt-ohm-milliammeters generally have a standardized arrangement, an example of which is shown in figure 47. The OHMS-AC-DC switch is used to select the unit being measured. The OHMS-ZERO-ADJ knob is used to zero-adjust the meter when ohms are measured. The various jacks around the outer edge are used to select the range of resistance, voltage, or current desired. When the OHMS-AC-DC switch is in the OHMS position one test lead is inserted in the common jack and the other is inserted in the range (R×1, R×10, R×100) desired. The leads are then shorted together and the ZERO-OHMS-ADJ knob is turned until the meter shows full-scale deflection. The unknown resistor then is placed across the two test leads and the value in ohms read directly on the meter scale. When measuring alternating or direct current or voltage, the OHMS-AC-DC switch is placed on the type of voltage or current being measured. The one test lead is inserted in the common jack and the other in the voltage or current range desired. The test leads then are applied across the voltage to be measured or in series with the circuit if current is being measured.

(3) The most common volt-ohm-milliammeters are those which measure only d-c voltage, direct current, and resistance, and those which measure a-c and d-c voltage, direct current, and resistance.

b. D-C VOLTAGE, CURRENT, AND RESISTANCE METERS.

(1) The circuit of a simple volt-ohm-milliammeter used to measure d-c voltage, current, and resistance is shown in figure 48. The circuits and ranges are selected by using pin jacks. For current measurements less than 1 ma, the test leads are plugged into the pin jacks marked 1 MA and COMMON. The current divides between the meter and the shunt, and the meter reading is proportional to the current through it. For currents between 10 and 100 ma, the 100 MA and COMMON terminals are used. Part of the current flows through R_3 and R_4, and the rest of the current flows through R_1, R_2, and the movement. For full-scale deflection, the current through the movement is the same as before, because decreasing the shunting resistance and increasing the resistance in series with the movement causes more current to flow through the shunt and less through the meter.

(2) When measuring voltage with this instrument, the multiplier resistor used depends on the full-scale deflection required. For example, if the voltage to be measured is between 10 and 100 volts, the test leads are plugged into the 100 V and COMMON jacks. The current from the circuit under test then divides between the meter and the shunt resistors, flows through the 100,000-ohm multiplier resistor, and back to the circuit under test. The circuit operation is the same for the other two voltage positions with the exception of the multiplier resistors. Because all the resistors in this meter circuit are fixed, the current through the meter is directly proportional to the voltage across the terminals and can be read directly on the meter.

(3) For resistance measurements, either the 1 MEG jack or the one marked 100,000 OHMS is used with the COMMON jack. Depending on which jack is used, the current from either the 15-volt or the 1.5-volt battery flows through the OHMS-ZERO-ADJ resistor (R_8 or R_{10}), the resistor being measured, the meter and its shunt resistors, the multiplier resistor (R_9 or R_{11}), and back to the battery. The larger the resistor being measured, the smaller the current, and the smaller the deflection of the meter needle. The resistance scale is cali-

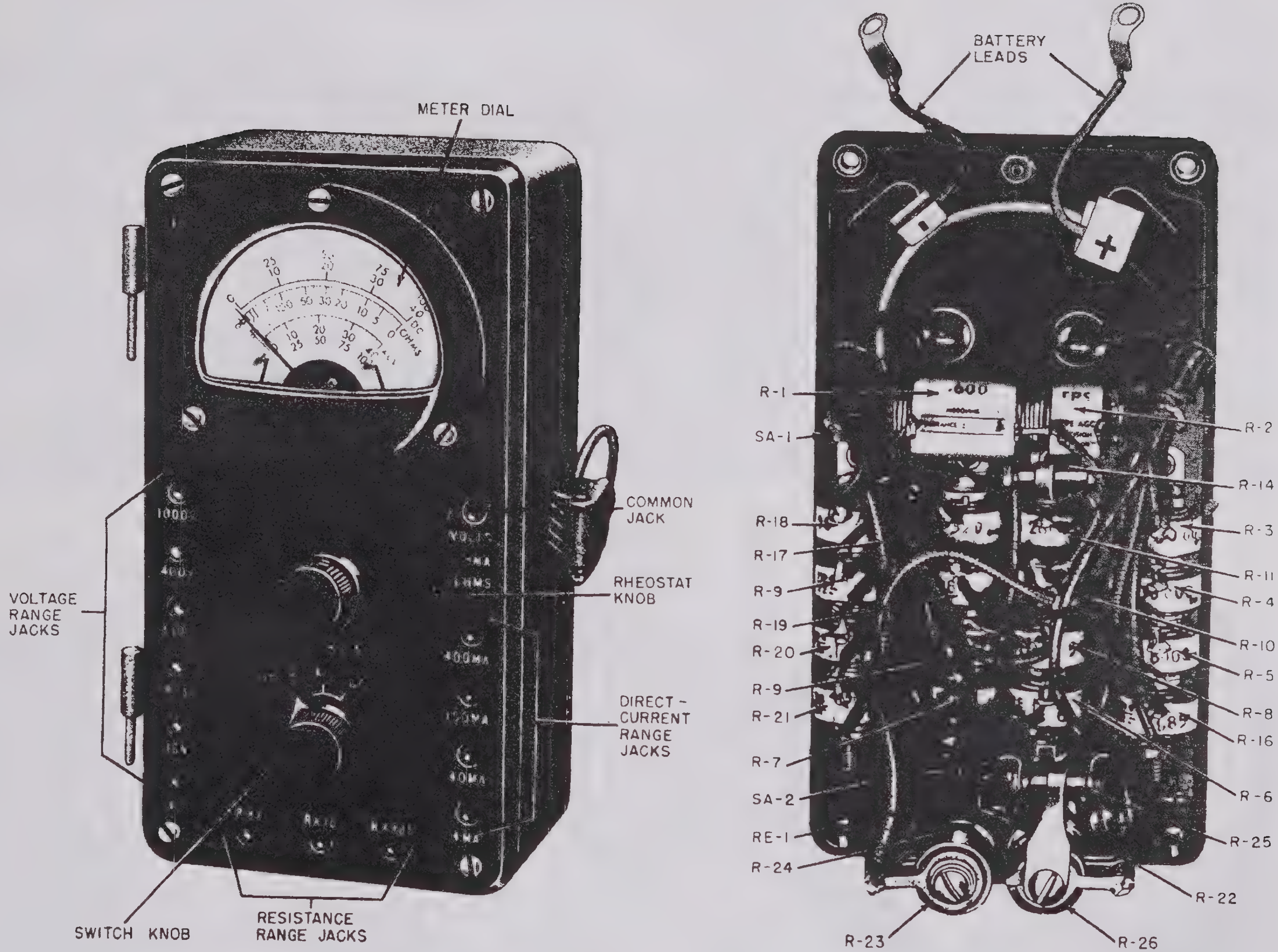


Figure 47. View of front and back panel of simple volt-ohm-milliammeter.

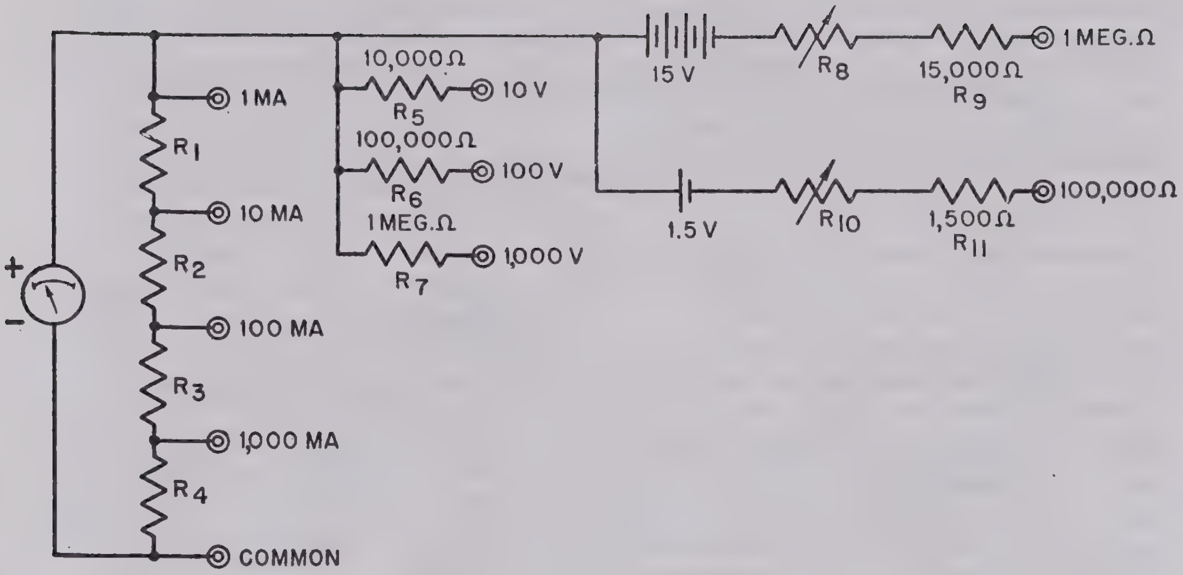


Figure 48. D-c volt-ohm-milliammeter circuit.

brated from right to left, and a small deflection indicates a large external resistance.

(4) The circuit of figure 48 has four direct-current ranges, three d-c voltage ranges, and two resistance ranges. Other meters of the same type may include more resistance ranges than provided here, as well as an increased number of voltage ranges. The circuit described here is limited in its application to d-c measurements. To extend its use to include a-c measurements, some type of rectifier circuit must be added.

c. A-C AND D-C VOLTAGE, DIRECT CURRENT, AND RESISTANCE METERS.

(1) Figure 49 is the circuit of a volt-ohm-milliammeter capable of measuring a-c and d-c voltages, direct current, and resistance. The voltage-measuring circuit consists of two sets of series multiplier resistors, one for d-c voltages, and the other for a-c voltages. When measuring d-c volts, the circuit selector switch is turned to the VOLTS position. One test lead then is inserted in the jack labeled COMMON and the other is plugged in the D-C VOLTS jack of the range desired. The meter movement is now shunted by the string of resistors immediately below it in the diagram, and is in series with the d-c multiplier resistors labeled D-C VOLTS.

(2) For a-c voltage measurements, the a-c multiplier resistors are used with their corresponding jacks. The germanium crystal is a half-wave rectifier feeding pulsating dc to the meter and its shunt. One test lead is inserted into the jack for the range desired and the other is inserted into the COMMON jack. When the polarity of voltage at the range jack is positive, current flows through the meter circuit. When the current reverses and the COMMON terminal is positive, current flows through the large resistor, R_R, and the multiplier resistor. This return circuit on the negative half-cycle is necessary to keep high negative voltages off the rectifier crystal. Although the resistance of the crystal

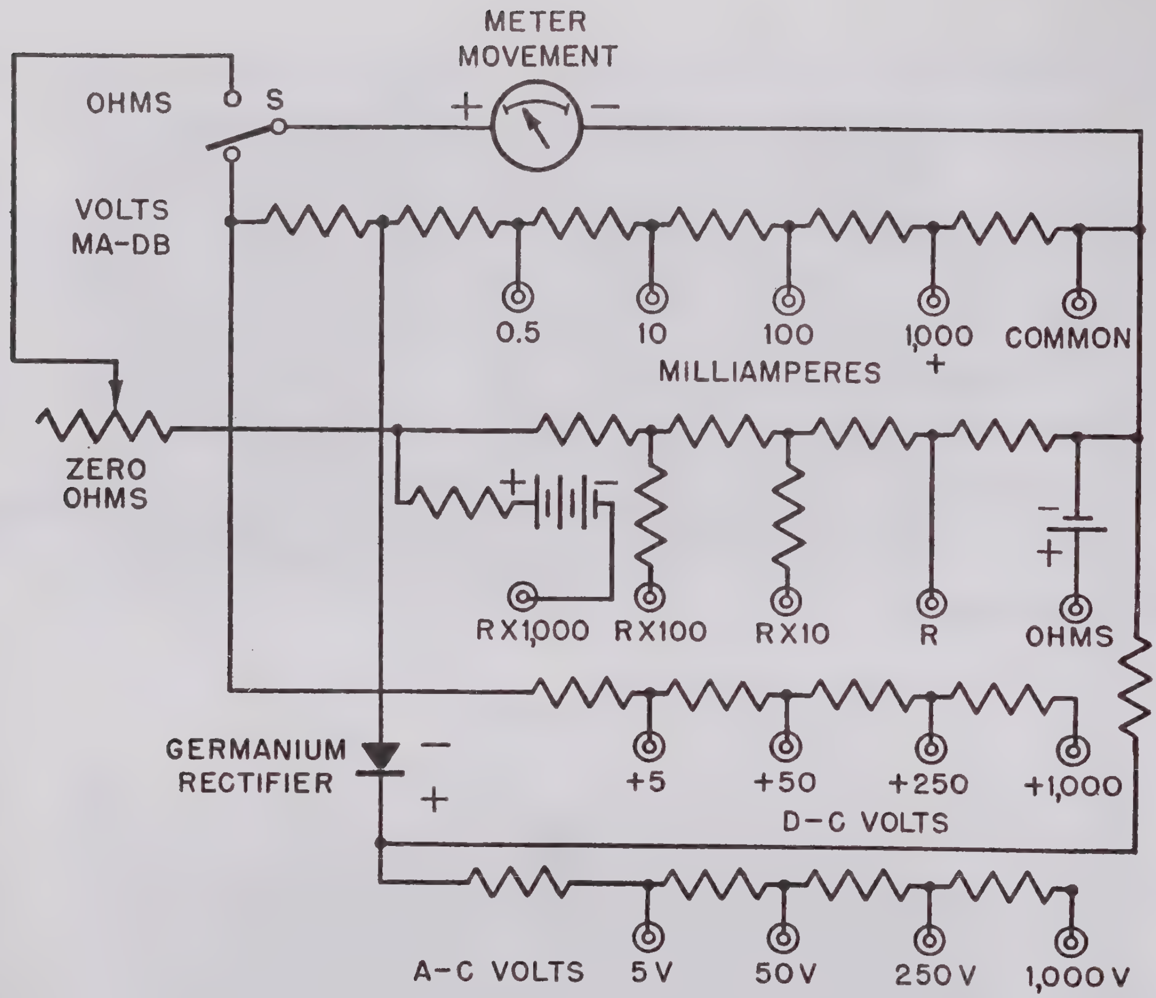


Figure 49. Basic circuit of a-c, d-c volt-ohm-milliammeter.

rectifier on the negative alternation is large (approximately 60,000 ohms), it still passes a small current when its polarity is reversed. Therefore, if R_R is not included in the circuit excessive voltages may damage the crystal.

(3) Current and resistance measurements are made in the manner described for the circuit of figure 48. When the R×100 jack is used, an additional battery, generally about 4.5 volts, provides enough current through the circuit for a convenient meter reading. For all resistance measurements, the test leads are plugged in the jack labeled OHMS and either the R, R×10, R×100, or R×1,000 jack, depending on the range desired.

42. Electronic Multimeter

a. GENERAL. The electronic multimeter is a vacuum-tube voltmeter circuit used to measure a-c and d-c voltages and resistance. It is similar to the vtvm in appearance, and the panel switches and jacks are the same as those used in the volt-ohm-milliammeter.

b. TYPICAL CIRCUIT.

(1) The block diagram in figure 50 is that of an electronic multimeter capable of measuring a-c and d-c voltages and

resistance. For a-c voltage measurements, the a-c rectifier probe is used and pulsating dc output is fed to selector switch S_1. For d-c voltage measurements, the d-c isolating probe is used. Selector switch S_1 is a six-pole, six-position wafer switch that turns the power on and selects the type of measurement. Range switch S_2 is a four-pole, nine-position wafer switch used to obtain the desired range for each type of measurement. A d-c degenerative amplifier maintains a high input resistance and provides a low output resistance to match the resistance of the meter movement. The balancing diode, V_2, is used to buck out the contact potential of the rectifier tube in the a-c probe. The power supply furnishes d-c voltages to operate the vacuum tubes used, and the battery is part of the ohmmeter section of the multimeter.

(2) The six sections of the function selector switch are shown in the upper left portion of the complete schematic diagram in figure 51. The ON-OFF switch, S_1-7, is in the primary circuit of the power supply transformer, and the four sections of the range switch are shown in the lower left portion. The range switch is set on the 2_V-R$\times$1 position. Section 1 of the range switch controls the balancing voltage from V_2 on a-c measurements, section 2 controls the ohmmeter circuit attenuator, and section 4 is the voltmeter section attenuator. The two-tube amplifier, V_3 and V_4, is coupled through V_5 and the low-resistance neon glow tubes, V_6 and V_7, to the indicating meter.

(3) The method of connecting the ohmmeter circuit to the amplifier is shown in figure 52. The range switch is set to position 3 (R$\times$100). In this position, R_{34}, a 3,000-ohm resistor, is shunted across the amplifier and meter circuit. The voltage from the batteries is divided across R_{34} and the unknown resistor, and the vtvm is calibrated in terms of the voltage across R_{34}. R_3 is used to adjust the indicating meter needle to 0 before resistance measurements are made.

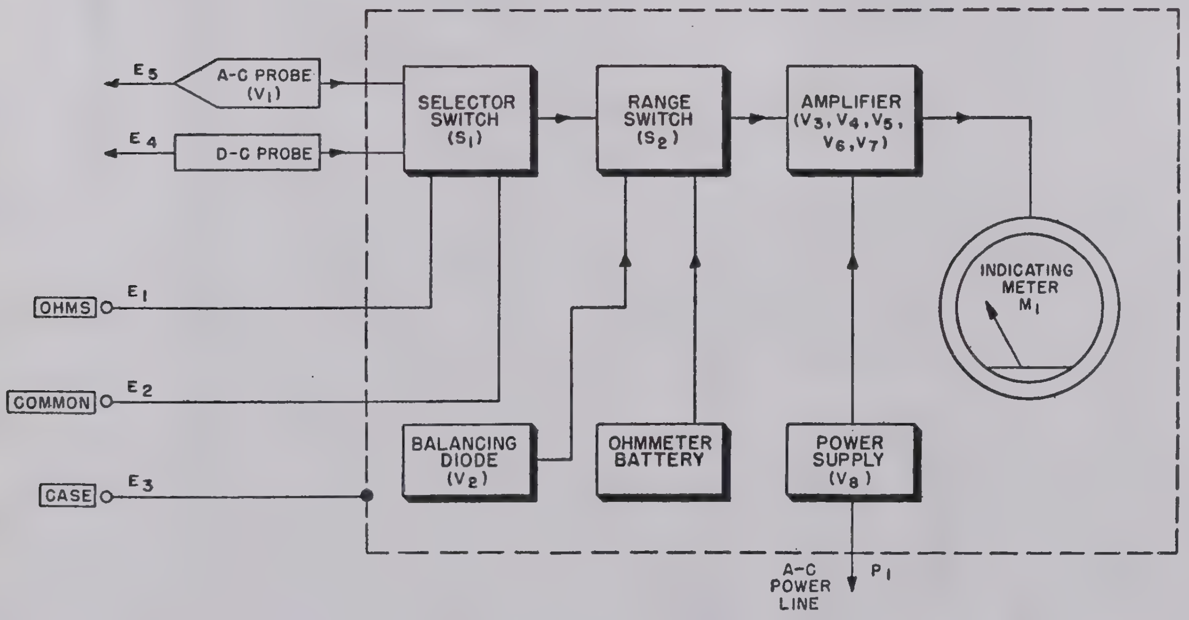


Figure 50. Block diagram of typical electronic multimeter.

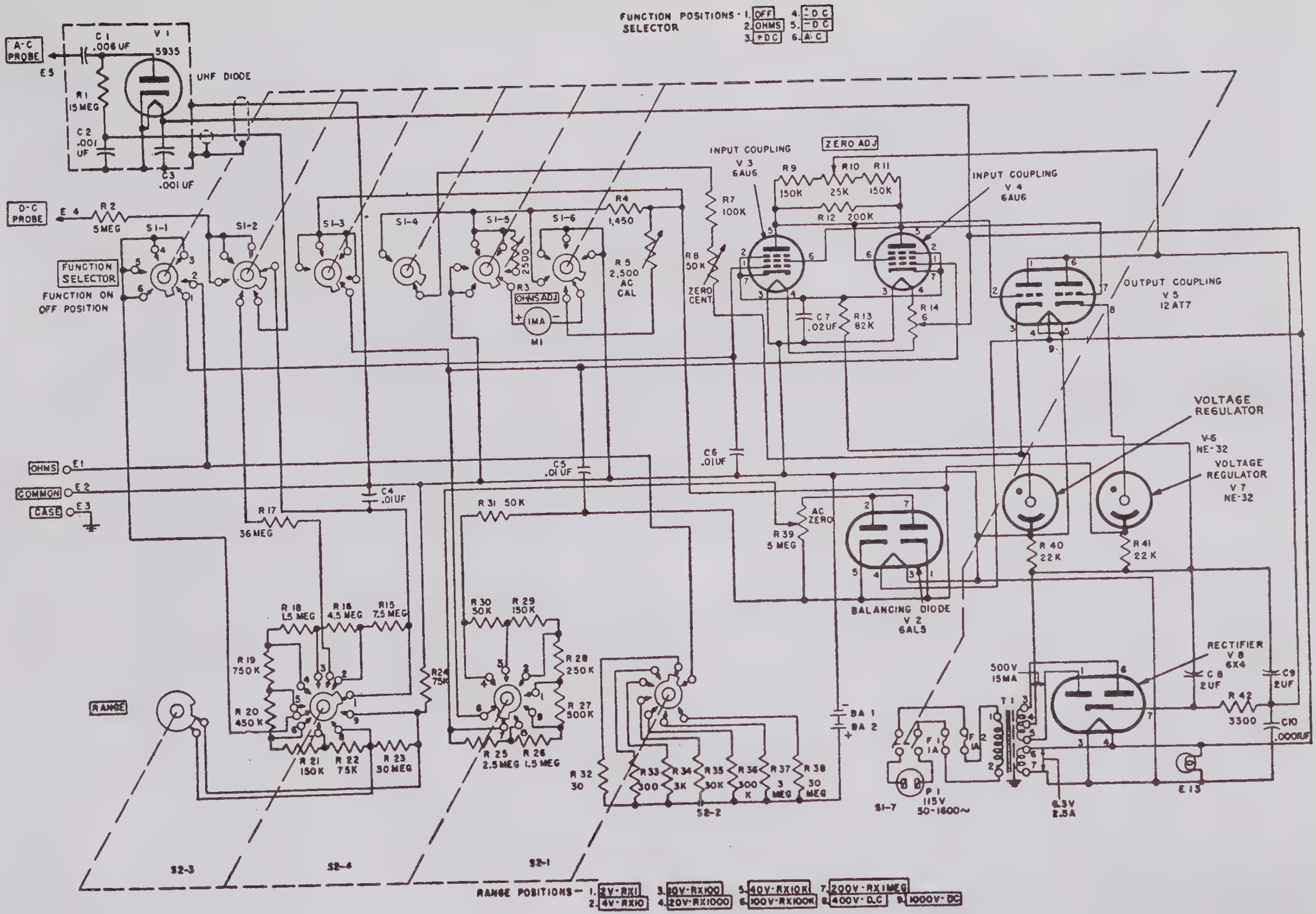


Figure 51. Schematic diagram of typical electronic multimeter.

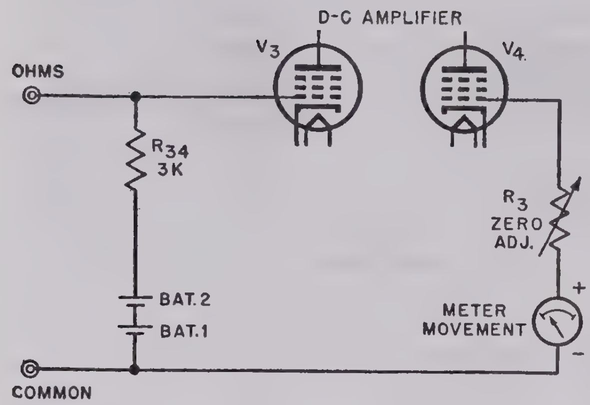


Figure 52. Simplified schematic of ohmmeter circuit for multimeter shown in figure 51.

(4) For d-c voltage measurements, a circuit similar to the simplified one in figure 53 is used. The d-c probe contains the 5-megohm resistor used to isolate the d-c section of the multimeter and minimize the loading effect of the voltmeter on the circuit under test. The input voltage is taken off the portion of the input attenuator from R_{18} to R_{22}, and is fed to the control grid of V_3. The indicating meter reads a voltage that is proportional to the input voltage. The negative terminal of the indicating meter is connected to the common terminal of the multimeter for the +d-c and ±d-c measurements. The positive terminal of the indicating meter is connected to COMMON for —d-c and a-c positions of the function selector switch. Section 4 of the function selector switch in figure 51 applies .5 ma through the indicating meter on the ±d-c ranges so that the meter reads midscale for 0 volts. Section 3 of S_2 shorts out resistor R_{23} on all ranges except the 1,000-volt setting. The total input resistance for all voltage ranges except the 1,000-volt range is 20 megohms (including the probe resistor). At the 1,000-volt setting the total input resistance is 50 megohms.

(5) A-c voltage measurements are accomplished by first rectifying the ac and then applying the resultant pulsating dc to attenuator S_2-4. A portion of this voltage then is taken off the attenuator and fed to the d-c amplifier (fig. 54). The voltage used to balance out the contact potential of the probe diode, V_1, is taken from the balancing-diode voltage divider and applied to the control grid of V_4. This voltage is adjusted to equal the contact potential of V_1 applied to the grid of V_3. The instrument is calibrated to read rms volts for sinusoidal voltages. The input impedance of this instrument on all a-c ranges is 6 megohms, with a shunting capacitance of 2 micromicrofarads.

(6) When measuring current on the vtvm, only the indicating meter and the necessary shunt circuits are used. The addition of an attenuator in parallel with the meter movement makes the meter capable of measuring direct current. Generally, the attenuator is used for current measurements from .1 ma to 1,000 ma. For measurements from 1 to 10 amperes, the total attenuator resistance is in series with the meter movement, and a small resistor is shunted across the input. A separate set of pin jacks generally is used for current measurements.

c. Output Power Ranges. The a-c output power of an audio or power amplifier can be obtained by measuring the a-c voltage across the output load resistor, squaring this value, and dividing by the value of the load resistance. Electronic multimeters capable of measuring a-c voltages usually have a scale which translates output voltage readings into relative power values in terms of decibels.

43. Using Multimeter

a. General Precautions.

(1) Before using any multimeter, carefully read and observe all of the instructions covering its use in the instruction book furnished with it. When using any instrument, the

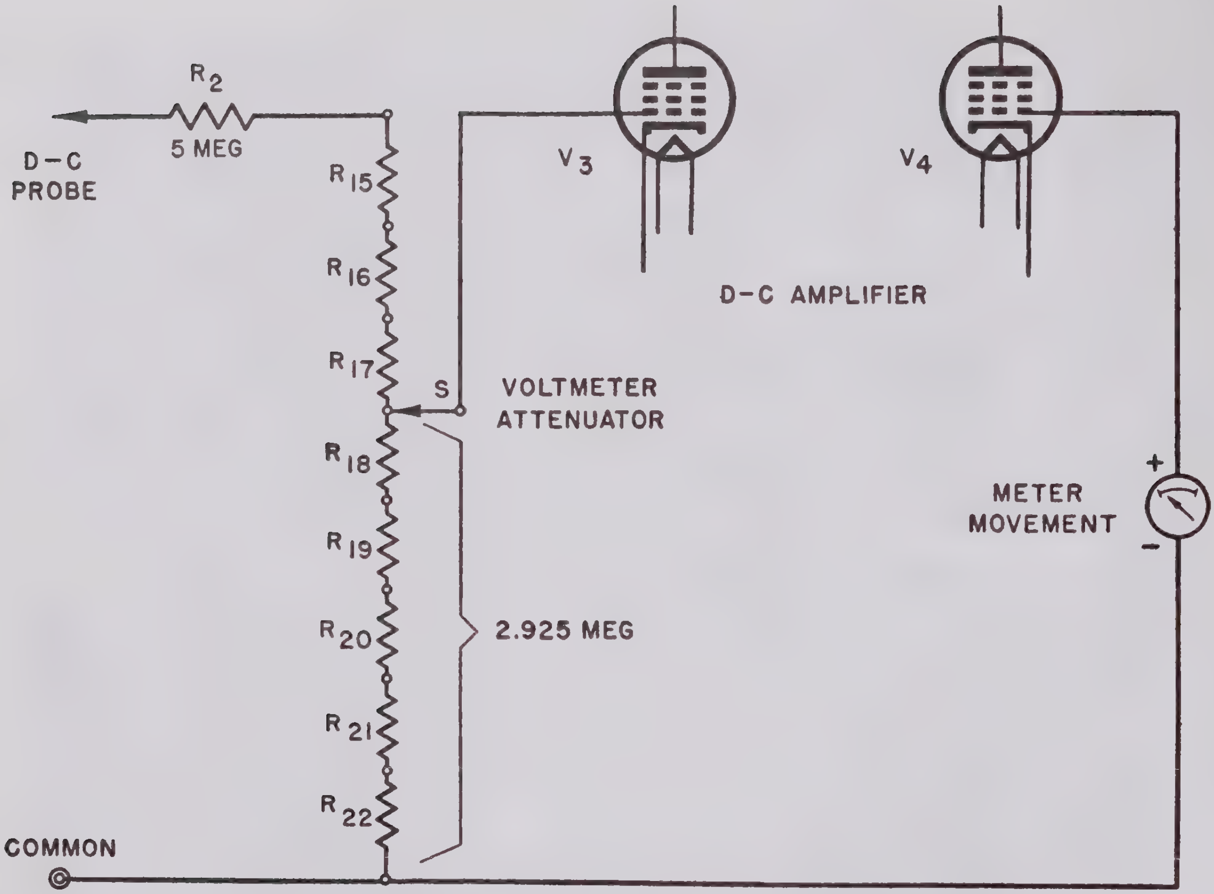


Figure 53. Simplified d-c voltage-measuring circuit of multimeter shown in figure 51.

front panel, particularly the area around the jacks and terminals, should be clean and dry. This prevents surface leakage which acts as a shunt and may cause an appreciable error in readings on the more sensitive ranges of the instrument.

(2) The following practices should be observed when using a multimeter on any of its ranges:

(a) When the instrument has a zero adjustment, the needle should be adjusted to 0 before any readings are taken. Electronic multimeters generally have two zero-adjust knobs on the front panel. One knob is used for setting the voltmeter to zero indication by balancing the d-c amplifier, and the other for setting the ohmmeter to indicate full-scale value with the test leads open-circuited. Multimeters of the volt-ohm-milliammeter variety do not require external zero-adjust controls for their voltage and current measuring ranges. Panel zero-adjust controls for ohmmeter circuits using batteries are always necessary to compensate for the degeneration of the batteries. If the needle cannot be brought to 0 by means of the panel adjustment knobs, additional controls usually are available within the instrument. Instructions for adjusting these controls are found in the instrument manual.

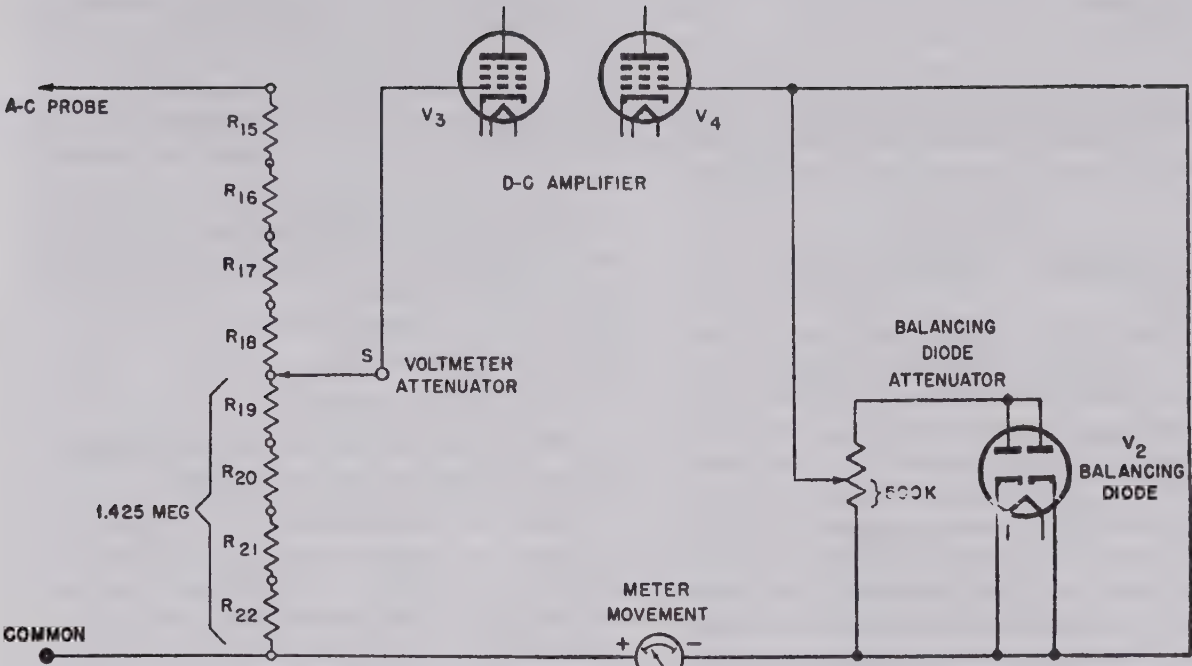


Figure 54. Simplified schematic of a-c voltage-measuring circuit of multimeter shown in figure 51.

(*b*) Set the range switch to the highest range for voltage or current measurements before making the measurement. For example, when measuring d-c voltage with a meter whose d-c voltage ranges are 0 to 10, 0 to 50, 0 to 250, 0 to 500, and 0 to 1,000, the initial range setting on the meter should be for the 0 to 1,000 range. This will protect the meter against damage from voltages which are higher than expected.

(*c*) When using electronic multimeters, the voltage and frequency of the power source must be within the values given in the equipment manual accompanying the instrument.

(*d*) Before making resistance measurements, be sure that no voltage exists in the circuit under test. *Discharge all capacitors.* The presence of any voltage through the external resistance in addition to the voltage of the battery in the ohmmeter circuit can damage the meter.

(*e*) The rotary switches on the front panel generally are not continuously rotatable. *Do not try to force them beyond the first or last position.*

(*f*) Observe all of the precautions listed in the previous chapters of this manual for the prevention of damage to meters and for obtaining accuracy of readings.

b. FUNCTIONS. The multimeter is used wherever a voltmeter, ammeter, or ohmmeter is needed for trouble-shooting electronic equipment. Voltage and current measurements are made on a circuit to locate the part in which a defect exists. The ohmmeter section of the multimeter then is used for checking the value of resistors, checking capacitors for leakage, and locating grounds, short circuits, and open circuits. *The ohmmeter tests must be made with no power applied to the circuit under test.*

44. Summary

a. A multimeter is a single instrument consisting of a case, two or more types of measuring circuits, and an indicating meter.

b. The indicating meter used in multimeters generally has a d'Arsonval moving-coil movement.

c. The two basic multimeters are the volt-ohm-milliammeter and the electronic multimeter.

d. The volt-ohm-milliammeter uses conventional voltmeter, ammeter, and ohmmeter circuits as described in chapters 2, 3, and 4.

e. Electronic multimeters are a combination of a vacuum-tube voltmeter with conventional ammeter and ohmmeter circuits.

f. The various measuring circuits of a multimeter usually are selected by means of a rotary switch and a set of pin jacks for the test leads.

g. Two scales are necessary on the indicating meter. One scale is calibrated for the voltage and current ranges of the instrument, the other for the resistance ranges. The various ranges for each type of measurement are selected by either a rotary switch or pin jacks.

h. Volt-ohm-milliammeters generally have a sensitivity of 1,000 or 20,000 ohms per volt for voltage measurements.

i. A d-c volt-ohm-milliammeter uses a variable resistor to shunt the meter when current measurements are taken; a set of series multiplier resistors plus the shunting resistance for voltage measurements; a battery, a series resistor, and the meter-shunting resistor for resistance measurements.

j. To measure a-c voltage with the volt-ohm-milliammeter, a copper-oxide or germanium-crystal rectifier is inserted in series with the meter movement. The indicating meter gives the *average* value of the resultant pulsating dc and is calibrated in terms of *rms* volts.

k. A typical electronic multimeter consists of an a-c rectifier probe, a d-c isolating probe, a shunt and series resistance network, a d-c amplifier, a d'Arsonval-type meter movement, and a power-supply circuit. A conventional ohmmeter circuit is included to measure resistance.

l. When using a multimeter, observe all the precautions listed in the equipment manual, as well as all the other precautions necessary for protection of the meter.

45. Review Questions

a. What is a multimeter?

b. What is the function of the rotary selector switches on the panel of a multimeter?

c. If the d-c voltage scale of a multimeter is calibrated with values for 0 to 10, 0 to 50, and 0 to 250 volts, explain how a 300-volt reading can be made if the range selector switch has positions of 10, 50, 250, and 500 volts.

d. What are the two basic types of multimeters? What is the difference between them?

e. Draw the circuit and explain the operation of a typical d-c volt-ohm-milliammeter.

f. Add an a-c voltage measuring circuit to the meter drawn in answer to question 5 and explain its operation.

g. What are the major elements of the a-c voltage measuring circuit of a typical *electronic* multimeter? Draw a circuit diagram showing these elements directly connected for a-c voltage measurements.

h. What voltage range setting of the range selector switch of a multimeter is used for the initial voltage measurement in a circuit?

i. How is the ohmmeter section of a multimeter adjusted to read the correct resistance for all succeeding measurements?

ANSWER SHEET

EST NO. ______________ PART ______ TITLE OF POSITION ______________________________
(AS GIVEN IN EXAMINATION ANNOUNCEMENT - INCLUDE OPTION. IF ANY)

LACE OF EXAMINATION ______________________________ ______________ DATE ______
(CITY OR TOWN) (STATE)

RATING

USE THE SPECIAL PENCIL. MAKE GLOSSY BLACK MARKS.

1 A B C D E	26 A B C D E	51 A B C D E	76 A B C D E	101 A B C D E
2 A B C D E	27 A B C D E	52 A B C D E	77 A B C D E	102 A B C D E
3 A B C D E	28 A B C D E	53 A B C D E	78 A B C D E	103 A B C D E
4 A B C D E	29 A B C D E	54 A B C D E	79 A B C D E	104 A B C D E
5 A B C D E	30 A B C D E	55 A B C D E	80 A B C D E	105 A B C D E
6 A B C D E	31 A B C D E	56 A B C D E	81 A B C D E	106 A B C D E
7 A B C D E	32 A B C D E	57 A B C D E	82 A B C D E	107 A B C D E
8 A B C D E	33 A B C D E	58 A B C D E	83 A B C D E	108 A B C D E
9 A B C D E	34 A B C D E	59 A B C D E	84 A B C D E	109 A B C D E
10 A B C D E	35 A B C D E	60 A B C D E	85 A B C D E	110 A B C D E

Make only ONE mark for each answer. Additional and stray marks may be counted as mistakes. In making corrections, erase errors COMPLETELY.

11 A B C D E	36 A B C D E	61 A B C D E	86 A B C D E	111 A B C D E
12 A B C D E	37 A B C D E	62 A B C D E	87 A B C D E	112 A B C D E
13 A B C D E	38 A B C D E	63 A B C D E	88 A B C D E	113 A B C D E
14 A B C D E	39 A B C D E	64 A B C D E	89 A B C D E	114 A B C D E
15 A B C D E	40 A B C D E	65 A B C D E	90 A B C D E	115 A B C D E
16 A B C D E	41 A B C D E	66 A B C D E	91 A B C D E	116 A B C D E
17 A B C D E	42 A B C D E	67 A B C D E	92 A B C D E	117 A B C D E
18 A B C D E	43 A B C D E	68 A B C D E	93 A B C D E	118 A B C D E
19 A B C D E	44 A B C D E	69 A B C D E	94 A B C D E	119 A B C D E
20 A B C D E	45 A B C D E	70 A B C D E	95 A B C D E	120 A B C D E
21 A B C D E	46 A B C D E	71 A B C D E	96 A B C D E	121 A B C D E
22 A B C D E	47 A B C D E	72 A B C D E	97 A B C D E	122 A B C D E
23 A B C D E	48 A B C D E	73 A B C D E	98 A B C D E	123 A B C D E
24 A B C D E	49 A B C D E	74 A B C D E	99 A B C D E	124 A B C D E
25 A B C D E	50 A B C D E	75 A B C D E	100 A B C D E	125 A B C D E

ANSWER SHEET

TEST NO. ____________ PART ______ TITLE OF POSITION ______________________________
(AS GIVEN IN EXAMINATION ANNOUNCEMENT - INCLUDE OPTION, IF ANY)

PLACE OF EXAMINATION ______________________________ ______________ DATE __________
(CITY OR TOWN) (STATE)

RATING

USE THE SPECIAL PENCIL. MAKE GLOSSY BLACK MARKS.

1 A B C D E	26 A B C D E	51 A B C D E	76 A B C D E	101 A B C D E
2 A B C D E	27 A B C D E	52 A B C D E	77 A B C D E	102 A B C D E
3 A B C D E	28 A B C D E	53 A B C D E	78 A B C D E	103 A B C D E
4 A B C D E	29 A B C D E	54 A B C D E	79 A B C D E	104 A B C D E
5 A B C D E	30 A B C D E	55 A B C D E	80 A B C D E	105 A B C D E
6 A B C D E	31 A B C D E	56 A B C D E	81 A B C D E	106 A B C D E
7 A B C D E	32 A B C D E	57 A B C D E	82 A B C D E	107 A B C D E
8 A B C D E	33 A B C D E	58 A B C D E	83 A B C D E	108 A B C D E
9 A B C D E	34 A B C D E	59 A B C D E	84 A B C D E	109 A B C D E
10 A B C D E	35 A B C D E	60 A B C D E	85 A B C D E	110 A B C D E

Make only ONE mark for each answer. Additional and stray marks may be counted as mistakes. In making corrections, erase errors COMPLETELY.

11 A B C D E	36 A B C D E	61 A B C D E	86 A B C D E	111 A B C D E
12 A B C D E	37 A B C D E	62 A B C D E	87 A B C D E	112 A B C D E
13 A B C D E	38 A B C D E	63 A B C D E	88 A B C D E	113 A B C D E
14 A B C D E	39 A B C D E	64 A B C D E	89 A B C D E	114 A B C D E
15 A B C D E	40 A B C D E	65 A B C D E	90 A B C D E	115 A B C D E
16 A B C D E	41 A B C D E	66 A B C D E	91 A B C D E	116 A B C D E
17 A B C D E	42 A B C D E	67 A B C D E	92 A B C D E	117 A B C D E
18 A B C D E	43 A B C D E	68 A B C D E	93 A B C D E	118 A B C D E
19 A B C D E	44 A B C D E	69 A B C D E	94 A B C D E	119 A B C D E
20 A B C D E	45 A B C D E	70 A B C D E	95 A B C D E	120 A B C D E
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